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Technology Inventory: Energy Efficiency Measures for Residental, Commercial, and Industrial Sectors in the United States.

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Abbreviations and Acronyms

AC	Air Conditioner
ACU	Atmospheric Crude Unit
ACEEE	American Council for an Energy-Efficient Economy
ACES	American Energy and Security Act
AEO	Annual Energy Outlook
AGR	Acid Gas Removal
BTO	US DOE Building Technologies Office
CBECS	Commercial Building Energy Consumption Survey
CCE	Cost of Conserved Energy
CCFL	Cold Cathode Fluorescent Lamp
CCU	Catalytic Cracking Unit
CDU	Crude Distillation Unit
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CFL	Compact Fluorescent Light
CKU	Coking Unit
CLASP	Collaborative Labeling and Appliance Standards Program
CPUC	California Public Utilities Commission
CRT	Cathode Ray Tube
DC	Direct Current
DEER	Database for Energy Efficiency Resources
DSIRE	Database of State Incentives for Renewable & Efficiency
DSM	Demand Side Management
EERS	Energy Efficiency Resource Standard
EE	Energy Efficiency
EF	Energy Factor
EM&V	Evaluation, Measurement & Verification
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
GPU	Gas Processing Unit
HID	High Intensity Discharge
HVAC	Heating, Ventilating, and Air Conditioning
IEA	International Energy Agency

IOU	Investor Owned Utility
IRP	Integrated Resource Plan
IRP	Integrated Resource Planning
ISBL	Inside Battery Limits
ISO	Independent System Operator
KERI	Korea Electro-technology Research Institute
LBNL	Lawrence Berkeley National Laboratory
LCC	Life Cycle Cost
LCD	Liquid Crystal Display
LEC	Light Emitting Capacitor
LED	Light Emitting Diode
LPS	Low Pressure Sodium
MECS	Manufacturing Energy Consumption Survey
MEMD	Michigan Energy Measures Database
MEPS	Minimum Energy Performance Standard
NEEP	Northeast Energy Efficiency Partnership
NPV	Net Present Value
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
NWPPC	Northwest Power Planning Council
OLED	Organic Light Emitting Diode
ORNL	Oak Ridge National Laboratory
PBP	Payback Period
PGE	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
RECS	Residential Energy Consumption Survey
RFP	Request for Proposal
RPS	Renewable Portfolio Standard
SBC	System Benefit Charge
SCE	Southern California Edison
SCG	Southern California Gas
SDGE	San Diego Gas & Electric
SRU	Sulfur Recovery Unit
UPS	Uninterruptable Power Supply

US DOE	United States Department of Energy
US EIA	United States Energy Information Administration
VDU	Vacuum Distillation Unit
VDPS	Vermont Department of Public Service
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

State Acronyms

AL	Alabama	MT	Montana
AK	Alaska	NC	North Carolina
AR	Arkansas	ND	North Dakota
AZ	Arizona	NE	Nebraska
CA	California	NH	New Hampshire
CO	Colorado	NJ	New Jersey
CT	Connecticut	NM	New Mexico
DC	District of Columbia	NV	Nevada
DE	Delaware	NY	New York
FL	Florida	OH	Ohio
GA	Georgia	OK	Oklahoma
HA	Hawaii	OR	Oregon
IA	Iowa	PA	Pennsylvania
ID	Idaho	PR	Puerto Rico
IL	Illinois	RI	Rhode Island
IN	Indiana	SC	South Carolina
KS	Kansas	SD	South Dakota
KY	Kentucky	TN	Tennessee
LA	Louisiana	TX	Texas
MA	Massachusetts	UT	Utah
MD	Maryland	VA	Virginia
ME	Maine	VT	Vermont
MI	Michigan	WA	Washington
MN	Minnesota	WI	Wisconsin
MO	Missouri	WV	West Virginia
MS	Mississippi	WY	Wyoming

Abstract

Energy efficiency is expected to continue to be one of main levers for governments to address the energy and climate crisis. While a diverse mix of energy efficiency programs has been regarded as an important part of governmental actions, an energy efficiency policy or program needs to identify and assess eligible savings measures, i.e., specific technologies or practices, for designing key features, e.g., target type, target stringency, covered load, and cost recovery. This report briefly discusses U.S. energy efficiency policies and programs, explores publicly available resources of energy efficiency measures for residential, commercial, and industrial sectors in the U.S., and describes how to compile key measures and characteristics into an integrated spreadsheet database. The database in the initial version offers, for more than 1,200 measures, efficiency or improvement potential, technical notes, costs at a given year, where applicable. Energy efficiency measures compiled here could play an important role in determining savings targets and target stringency under a potential energy efficiency policy such as an energy efficiency resource standard in Korea, and offer significant opportunities for energy efficiency improvement.

Chapter 1 Introduction

The Korea Electro-technology Research Institute (KERI) commissioned the International Energy Studies group at Lawrence Berkeley National Laboratory (LBNL) to undertake this technology inventory and analysis of energy efficiency improvement options explored in the United States (U.S.), in support of the potential Energy Efficiency Resource Standard (EERS) of Korea. The subsections below describe the background, objective, scope, and data sources for this project, and the organization of the remainder of this report.

1.1. Background

In Republic of Korea, i.e., South Korea, the Renewable Portfolio Standard (RPS) became effective in 2012 with a beginning renewable electricity quota of 2% of total generation for larger generators, rising to 10% in 2022 ([1]). The Korean government has a plan to formulate an EERS at the national level. Technical information on energy efficiency programs and measures that have been analyzed and discussed in the U.S. would be useful for South Korea to effectively develop its EERS, because the majority of energy efficient technologies are likely to be applicable across regions.

1.2. Objective, Scope, and Expected Benefits

The objective of this report as an initial study is to explore and summarize energy efficiency improvement options (or measures [1]), components, properties (including performance or improvement potential), and cost data (where available) that have been discussed and publicly available in the U.S.

The project explores existing databases of energy efficiency measures for residential, commercial, and industrial sectors in the U.S., develops a spreadsheet database that can list all selected measures with characteristics including improvement potential, and provides a list of resources where original data are available. The summarized spreadsheet database covers the key measures in each sector, e.g., appliances, ceiling/roofs, controls, lighting, motors, office equipment, refrigeration, space conditioning, windows, etc. This database sets out the main characteristics of energy efficiency improvement options in each sector and seeks to assess and report the efficiency

[1] Energy efficiency measures in this report refer to the specific technologies (e.g., efficient lighting fixture) and practices (e.g., duct sealing) that are used to achieve energy savings ([9]).

improvement (or energy savings) potential.

The most direct benefit of EERS is reduced energy consumption and corresponding savings in energy costs. Benefits also include potential reductions in capital costs related to building electric generation capacity, and in fossil fuel imports to the country. The up-to-date information this report has collected and the data to be updated along with the progress of the potential Korean EERS are also expected to be valuable inputs to future studies related to national—level energy efficiency policies and programs.

1.3. Data Sources

The analysis team obtained the data for this report from recent technical reports and databases publicly available in the U.S. and mostly published by federal or state institutions. Table 1 shows a list of useful data sources. The full list of resources used for this report is presented in References and Appendix A.[2] Finally, this report presents an approach that integrates existing data of energy efficiency measures by sector in the form of a spreadsheet database.

[2] As technologies continually change, we do not claim the energy efficiency measures (technologies) discussed in this report and the spreadsheet are the best or only options available.

Table1. Selected Data Sources for Energy Consumption, Energy Efficiency Policies and Measures

American Council for an Energy-Efficient Economy (ACEEE)	▪ Energy Efficiency Resource Standards ▪ Reports for Energy Efficiency Policies and Programs
California Public Utilities Commission (CPUC)	▪ Data of Energy Efficiency Resources (DEER) ▪ Energy Efficiency Statistics
Consortium for Energy Efficiency (CEE)	▪ CEE program resources (Residential, Commercial, and Industrial Sectors)
ENERGY STAR	Industrial Energy Efficiency Measures and Options ▪ Available for aluminum, brewing, cement, chemical, corn refining, food processing, glass, metal casting, motor vehicle manufacturing, petrochemical, petroleum refining, pharmaceuticals, pulp & paper, ready mix concrete, iron & steel, textiles (prepared by LBNL)
Lawrence Berkeley National Laboratory (LBNL)	▪ Technical Reports for Appliances, Equipment, Buildings, and Industrial Energy Efficiency
Michigan Public Service Commission	▪ Michigan Energy Measures Database (MEMD)
National Renewable Energy Laboratory (NREL)	▪ National Residential Efficiency Measures Database
Northeast Energy Efficiency Partnership (NEEP)	▪ Regional Energy Efficiency Database
Natural Resources Defense Council (NRDC)	▪ Technical Reports for Appliances and Equipment
Oak Ridge National Laboratory (ORNL)	▪ Technical Reports for Industrial Energy Efficiency
Pacific Northwest National Laboratory (PNNL)	▪ Technical Reports for Commercial Buildings
United States Department of Energy (US DOE)	▪ Technical Support Documents (for appliances and equipment) ▪ Building Technologies Office’s Reports (commercial buildings, solid-state lighting, emerging technologies, etc.)
United States Energy Information Administration (US EIA)	Energy consumption by sector and end-use ▪ Annual Energy Outlook ▪ Residential Energy Consumption Survey (RECS) ▪ Commercial Building Energy Consumption Survey (CBECS) ▪ Manufacturing Energy Consumption Survey (MECS)
Vermont	▪ Vermont Energy Efficiency Potential Study

1.4. Organization of this Report

The remainder of this report is organized as follows:

Chapter 2 Energy Efficiency Policies and Programs presents an overview of the current energy efficiency policies and programs in the U.S.

Chapter 3 Energy Efficiency Measures and Databases discusses various types of energy efficiency measures (i.e., technologies or practices) across sector and publicly available data.

Chapter 4 LBNL's Database for Energy Efficiency Measures presents how LBNL integrates key elements of energy efficiency improvement options from identified data sets.

Chapter 5 Summary and Conclusions summarizes the previous chapters and offers conclusions and suggestions for future research.

Appendix A lists resources for energy efficiency by topic.

Chapter 2 Energy Efficiency Policies and Programs

In this chapter we briefly discuss U.S. energy efficiency policies and programs that include state-level EERS.

2.1 Energy Efficiency Policies and Programs

Improving the energy efficiency across sectors has been regarded as one of the most constructive, cost-effective ways to address the challenges of high energy prices, energy security and independence, air pollution, and climate change in the near future ([9]). In July 2006, the National Action Plan for Energy Efficiency presented the following five key recommendations for fully developing the cost-effective energy efficiency resources in the U.S. ([9]):

- Recognize energy efficiency as a high-priority energy resource.
- Make a strong, long-term commitment to implement cost-effective energy efficiency as a resource.
- Broadly communicate the benefits of and opportunities for energy efficiency.
- Promote sufficient, timely, and stable program funding to deliver energy efficiency where cost-effective.
- Modify policies to align utility incentives with the delivery of cost-effective energy efficiency and modify ratemaking practices to promote energy efficiency investments.

In 2008, the Leadership Group of the National Action Plan presented a framework that establishes a long-term aspirational goal (i.e., the goal to achieve all cost-effective energy efficiency by the year 2025) and ten key implementation goals for the 2025 Vision (see Table 2, [9])

Table2. Implementation Goals for Achieving All Cost-Effective Energy Efficiency by 2025

Goal One	Establishing Cost-Effective Energy Efficiency as a High-Priority Resource
Goal Two	Developing Processes to Align Utility and Other Program Administrator Incentives Such That Efficiency and Supply Resources Are on a Level Playing Field
Goal Three	Establishing Cost-Effectiveness Tests
Goal Four	Establishing Evaluation, Measurement, and Verification Mechanisms
Goal Five	Establishing Effective Energy Efficiency Delivery Mechanisms
Goal Six	Developing State Policies to Ensure Robust Energy Efficiency Practices
Goal Seven	Aligning Customer Pricing and Incentives to Encourage Investment in Energy Efficiency
Goal Eight	Establishing State of the Art Billing Systems
Goal Nine	Implementing State of the Art Efficiency Information Sharing and Delivery Systems
Goal Ten	Implementing Advanced Technologies

Source: National Action Plan for Energy Efficiency Vision for 2025: A Framework for Change (2008, [9]) Specifically, the National Action Plan is interrelated with state, regional, and federal policy areas that are designed to "*limit emission of GHGs; encourage the use of clean, efficiency distributed generation; promote clean energy supply such as renewable energy; promote load reductions at critical peak times through demand response; modernize and maintain the nation's electric transmission and distribution systems, including smart grid and advanced meter infrastructure; and maintain a sufficient reserve margin for reliable electricity supply"* ([9]). In 2009, the American Clean Energy and Security Act of 2009 (ACES) required electric utilities to meet 20% of their electricity demand through renewable energy sources and energy efficiency by 2020 (i.e., a combined RES-EERS), although it did not become law due to inaction in the Senate ([5]).

The utility-sector energy efficiency programs in the U.S., which launched initially in response to the energy crises in the 1970s, have been developed and expanded over time to yield energy and economic benefits, save money for customers, and reduce greenhouse gases (GHGs) ([2]-[3]). Energy efficiency in the U.S. has been pursued through a variety of policies and programs that include federal and state minimum energy performance standards (MEPS); building energy codes; a national efficiency labeling program (ENERGT STAR®); tax credits; and incentive programs (e.g., rebates) ([3]).

Energy efficiency in the utility sector can be defined as an energy resource that is capable of yielding energy and demand savings by displacing electricity generation from various supply-side resources ([2]). Utility investment policies in energy efficiency can be driven by system benefits charges (SBC); energy efficiency resource standard (EERS); renewable portfolio standard (RPS) under which energy efficiency can be a qualifying resource; requirements that utilities obtain "all cost-effective energy efficiency" resources; long-term integrated resource planning requirements; and demand-side management (DSM) requirements ([3]). Table 3 shows an overview of energy efficiency programs by type, and Table 4 presents such energy efficiency programs categorized as "policy drivers" by researchers from Lawrence Berkeley National Laboratory.

Table3. Overview of Energy Efficiency Programs

Policy Model	Description	Lead Administrator	Scope of Programs	Political Context
Portfolio Standard	The program administrator is subject to a portfolio standard expressed in terms of percentage of overall energy or demand. This model can include gas as well as electric, and can be used independently or in conjunction with an SBC or IRP requirement.	Utility may implement programs or buy to meet standard	Programs for all customer classes	Generally used in states with existing programs to increase program activity
Systems Benefits Charge (SBC)	A charge on a consumer's bill from an electric distribution company that helps pay for the costs of certain public benefits program such as low-income assistance, energy efficiency programs, and public interest R&D efforts The charge is usually a fixed amount per kWh or MBTU.	Utility	Programs for all customer classes	Most programs of this type came out of a restructuring settlement in states where there was an existing infrastructure at the utilities
		State agency Third party	Programs for all customer classes	Most programs of this type came out of a restructuring settlement
Integrated Resource Plan (IRP)	Energy efficiency, along with other demand-side options, is treated on an equivalent basis with supply. Cost recovery can either be in base rates or through a separate charge.	Utility	Program type dictated by resource need	Part of IRP requirement; may be combined with other models

Author's edits based on [10]

Table4. Policy Drivers for Customer-Funded Energy Efficiency Program Activity

Key Policy Drivers for Energy Efficiency Spending and Savings	Applicable to Electric Efficiency Programs	Applicable to Natural Gas Efficiency Programs
Energy Efficiency Resource Standard (EERS)[a]	AZ, CA, CO, HI, IL, IN, MD, MI, MN, MO, NM, NY, OH, PA, TX	CA, CO, MI, MN, NY, IL
Energy efficiency eligibility under state RPS	HI, MI, NC, NV, OH	
Statutory requirement that utilities acquire all cost-effective energy efficiency	CA, CT, MA, RI, VT, WA	CA, CT, MA, RI, VT, WA
Systems benefit charges (SBC)	CA[b], CT, DC, MA, ME, MT, NH, NJ, NY, OH, OR, RI, VT, WI	CA, DC, ME, MT, NJ, NY, RI,WI
Integrated resource planning (IRP)	34 States (primarily in the West and Southeast) and TVA	17 States (primarily in the West and Northeast)
Demand Side Management (DSM) plan or multiyear energy efficiency budget	28 States	21 States (primarily in the Northeast and Midwest)

Source: Barbose et al., 2013 (LBNL, [3])

[a] Note that LBNL's criteria that define EERS are slightly different from those of other organizations and count only 15 states as having an EERS (see Section 2.2).

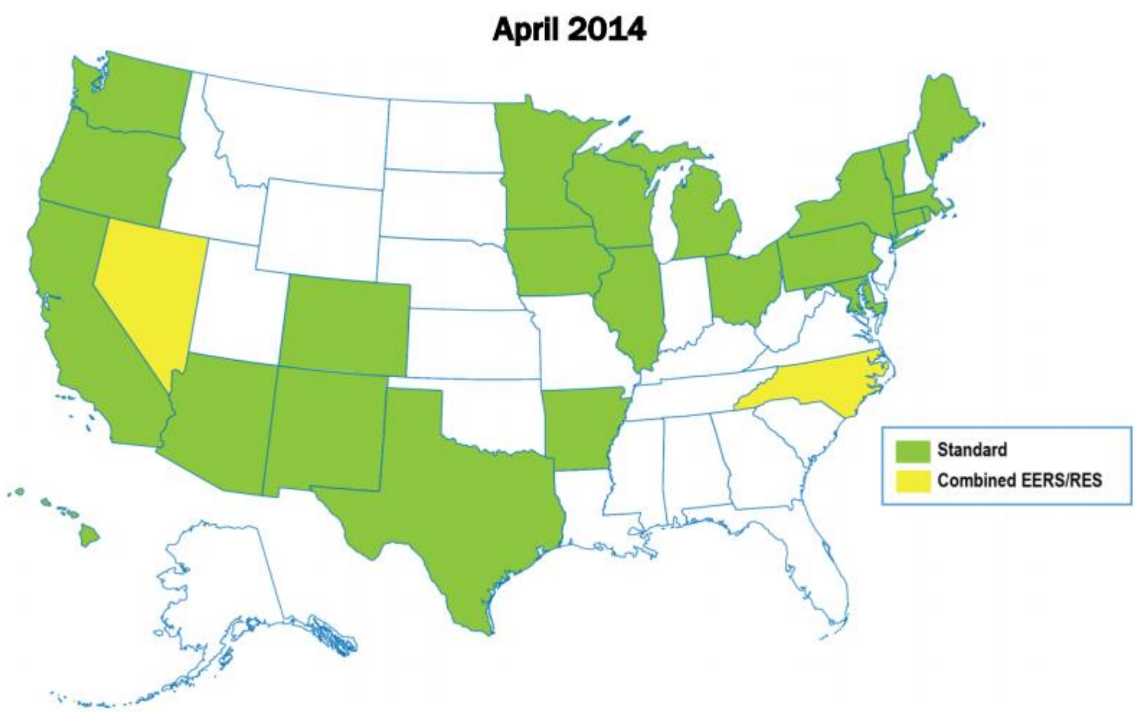
[b] Although the systems benefit charge in California was to expire at the end of 2011, it has been extended to 2020([43]). See Table 3 for details of each policy driver.

2.2 Energy Efficiency Resource Standard (EERS)

2.2.1. Overview of EERS Policies

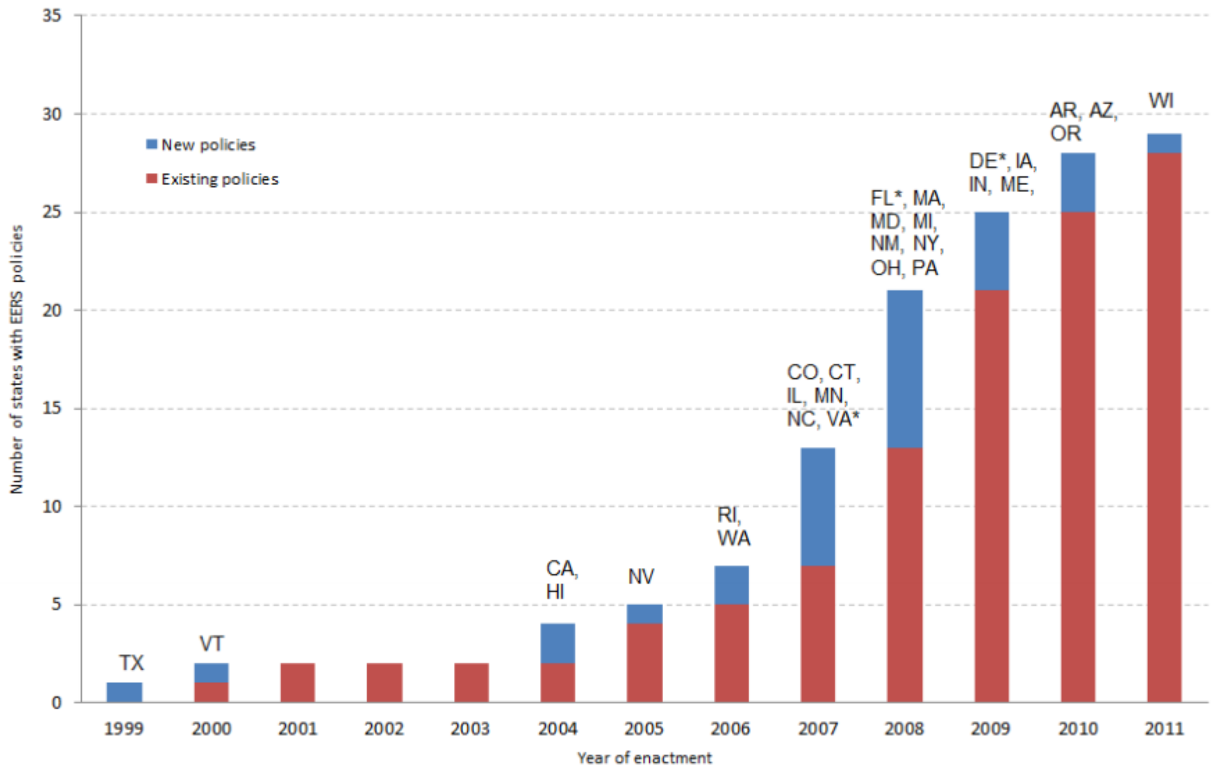
Energy efficiency resource standards (EERSs) or energy efficiency portfolio standards (EEPSs) account for majority of recent energy efficiency policies, while a diverse mix of energy efficiency programs has been regarded as an important part of utility investment portfolios for decades ([3], [6]). EERS policies in the U.S. began to emerge in the late 1990s when the importance of energy efficiency was refocused with electric system reliability issues ([6]).

An EERS, similar to in concept to a RPS, is designed to establish specific, long-term energy (e.g., electricity and gas) savings targets that utilities or non-utility program administrators must meet through customer energy efficiency programs, and can be adopted through either legislation or regulation ([4]). Since Texas adopted the nation's first EERS in 1999, twenty-five states, which account for nearly 60% of electricity sales in the U.S., as of April 2014, have enacted long-term (over 3 years), binding energy savings targets or EERS ([4]-[6], see Figure 1 and 2). It is estimated that the total annual electricity savings would be more than 232 TWh by 2020, equivalent to over 6% of projected 2020 sales nationwide ([4]). Massachusetts, Rhode Island, and Vermont have the strongest EERS requirements (see Table 5, [4]-[5]).



Source: ACEEE ([5], see Table 2 for EERS policy details)

Figure 1. States with EERS policies in place (as of April 2014)



Source: ACEEE ([6])
* These states have enacted EERS legislation but have not enacted rules for implementation or committed necessary funding to efficiency programs.

Figure 2. Year of Initial State EERS Adoption

EERS policies are different from other types of energy efficiency policies in that they do not mandate specific efficiency measures, but generally *require*[3] a minimum amount of savings and allow utilities to determine the best ways to achieve those savings ([11]). EERS policies in the U.S. are assessed to drive larger and more sustainable energy savings than traditional DSM or IRP requirements because long-term targets set under EERS policies help utilities incorporate energy efficiency into their long-term IRPs and improve energy efficiency programs according to the progress by monitoring them ([6]).

[3] Combined RPS-EERS policies *allow* a specified amount of energy efficiency rather than *requiring* it ([6]).

Table5. EERS Policy Details by State

State Year Enacted	Electricity	Natural Gas	State Year Enacted	Electricity	Natural Gas
Arizona 2010	22% cumulative electricity savings by 2020.	6% cumulative gas savings by 2020.	Nevada 2005, 2009	20% of retail electricity sales to be met by renewables and energy efficiency by 2015, and 25% by 2025. Energy efficiency may meet a quarter of the standard through 2014, but is phased out of the RPS by 2025.	-
Arkansas 2010	Annual reduction of 0.75% of total sales in 2014 and 0.9% in 2016.	Annual reduction of 0.4% of total sales in 2014 and 0.5% in 2015.	New Mexico 2008, 2013	5% reduction from 2005 total retail electricity sales by 2014 and an 8% reduction by 2020.	-
California* 2004, 2009	~0.9% annual savings through 2020 (demand reduction of 4,541 MW).	619 gross MMTherms between 2012 and 2020.	New York 2008	15% cumulative savings by 2015.	~14.7% cumulative savings by 2020.
Colorado 2007	0.8% of sales in 2011, increasing to 1.35% in 2015, and 1.66% in 2019.	Savings targets commensurate with spending targets (at least 0.5% of prior year's revenue).	North Carolina 2007	Renewable Energy and Energy Efficiency Portfolio Standard (REPS) requires renewable generation and/or energy savings of 6% by 2015, 10% by 2018, and 12.5% by 2021 and thereafter. Energy efficiency is capped at 25% of target, increasing to 40% in 2021 and thereafter.	-
Connecticut* 2007, 2013	Annual savings of ~1.4% through 2015.	Average annual savings of ~60 MMTherms through 2015.	Ohio 2008	22% reduction by 2025 (Peak demand reduction targets of 1% in 2009 and an additional 0.75% each year thereafter until 2018.	

Hawaii 2004, 2009	4,300 GWh reduction in electricity use by 2030 (equivalent to ~30% of forecast sales or 1.4% annual savings.	-	Oregon 2010	0.8% of 2009 sales in 2010, ramping up to 1.4% in 2013 and 2014.	0.2% of sales in 2010 ramping up to 0.4% in 2014.
Illinois* 2007	0.2% annual savings in 2008, ramping up to 1% in 2012, 2% in 2015 and thereafter. Annual peak demand reduction of 0.1% through 2018.	8.5% cumulative savings by 2020 (0.2% annual savings in 2011, ramping up to 1.5% in 2019).	Pennsylvania * 2004, 2008	3% cumulative savings from 2009 to 2013; ~2.3% cumulative savings from 2014-2016.	-
Iowa 2009	Varies by utility from 1-1.5% annually through 2014.	Varies by utility from 0.74-1.2% annually through 2014.	Rhode Island* 2006	Annual savings of 1.7% in 2012, 2.1% in 2013, 2.5% in 2014.	Annual savings of 0.6% in 2012, 0.8% in 2013, and 1.0% in 2014.
Maine* 2009	20% reduction by 2020, with annual savings targets of ~1.6%.	20% reduction by 2020, with annual savings targets of ~0.3%.	Texas* 1999, 2007	25% reduction in annual growth in demand 2012; 30% reduction in annual growth in demand 2013 (Peak demand reduction targets of 0.4% compared to previous year).	-
Maryland 2008	15% reduction in per capita consumption by 2015, compared to 2007; 15% reduction in per capita peak demand by 2015, compared to 2007.	-	Vermont* 2000	Expected cumulative savings of ~6% from 2012 to 2014.	-

Massachusetts* 2009	1.4% reduction in 2010, increasing to 2.6% by 2015.	0.63% reduction in 2010, increasing to 1.15% by 2015.	Washington* 2006	Biennial and Ten-Year Goals vary by utility. Law requires savings targets to be based on the Northwest Power Plan, which estimates potential annual savings of about 1.5% through 2030 for Washington utilities.	-
Michigan 2008	0.3% annual savings in 2009, ramping up to 1% in 2012 and continuing through 2015.	0.10% annual savings in 2009, ramping up to 0.75% in 2012 and continuing through 2015.	Wisconsin* 2011	Annual savings of ~0.66% of sales in 2011-2014.	Annual savings of ~0.5% of sales in 2011-2014.
Minnesota 2007	1.5% annual savings in 2010 and thereafter.	0.75% annual savings from 2010-2012; 1% annual savings in 2013 and thereafter.			

* Utilities in these states must pursue all cost-effective efficiency resources, or energy efficiency measures selected under EERS may not exceed an established cost-cap.

Source: Author’s edits based on ACEEE ([5], as of April 2014), www.dsireusa.org (as of February 2014)

2.2.2. Definitions and Distinctions of EERS

As seen in Table 5, EERS policies differ from state to state, although each state has established their EERS from long-term perspectives on the role of energy efficiency in the states' energy portfolio ([3]-[6]). The American Council for an Energy-Efficient Economy (ACEEE)[4] has found that EERS policies are divided into three categories in terms of policy approach; 1) a statewide EERS, 2) a set of long-term energy savings targets tailored to each utility, and 3) an eligible resource incorporated into RPS, although the latter two approaches may be technically beyond the traditional definition ([7]). Table 6 summarizes the three EERS approaches categorized by ACEEE.

Table6. EERS Policy Approaches by State

Statewide EERS	Tailored Utility Target	Combined RPS-EERS
Typically set by state legislatures and codified by utility commissions, the statewide EERS calls for all eligible utilities to achieve a prescribed level of savings. In efficiency procurement states, the state legislatures have required utilities to invest in all cost-effective efficiency and the specific targets are then set by stakeholder councils and public utility commissions (PUCs).	Initiated in a variety of ways, long-term energy efficiency targets in these states are tailored to each specific utility. In each case, law or regulation calls for the establishment of multi-year (3+ year) specific savings targets.	Energy efficiency may be accepted as an eligible resource in state RPS. In these cases, energy efficiency is measures on a cumulative rather than annual, incremental basis.
<u>Legislated approach</u> ▪ Prescribed levels of savings (NY, MD, PA, MI, OH, IL) ▪ All cost-effective EE loading order (MA, RI) <u>Codified by utility commissions</u> ▪ Sets specific targets - All utilities must meet same savings requirements (as % of sales)	▪ Utilities (IA, CO) or third party administrators (OR, ME, VT) set their own targets ▪ Targets are approved by commissions	NV, NC

Source: ACEEE ([7]-[8])

According to ACEEE ([6]), an EERS must:

- Set clear long-term (three or more years) targets for electricity and/or natural gas savings
- Make clear that targets are mandatory
- Include sufficient funding for full implementation of programs necessary to meet targets

[4] The American Council for an Energy-Efficient Economy, a nonprofit, 501(c)(3) organization, acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors (www.aceee.org).

Several states (e.g., California, Connecticut, Massachusetts, Vermont, and Washington) have determined to enforce all cost-effective efficiency requirements. For example, Massachusetts' all cost-effective requirement translates into incremental savings targets reaching 2.6% of retail electricity sales by 2015 ([6]). While combined RPS-EERS policies make it difficult to measure success contributed directly from energy efficiency, utilities are expected to invest in energy efficiency to the extent that it is cost effective and allowable under the combined RPS-EERS since it is the lowest cost resource ([6]).

The National Renewable Energy Laboratory (NREL) defines an EERS as a *"policy that requires utilities or other entities to achieve a specified amount of energy savings within a specified time frame"* ([11]). NREL's definition largely aligns with ACEEE's definition, but it does not technically encompass combined RPS-EERS policies such as those of Nevada and North Carolina since such RPS-EERS policies *allow* a specified amount of energy efficiency rather than *requiring* it ([3], [6]). NREL notes that three *key features* required or suggested to design an EERS at the most fundamental level as follows ([11]):

- EERS must have quantitative targets specifying a required amount of energy savings over a specified period of time.
- An entity or group of entities is required to meet the targets and demonstrate compliance.
- A set of energy savings activities can be used to meet the targets.

LBNL researchers who have been tracking U.S. energy efficiency program activities define an EERS using the following three criteria ([3], [6]), (the first does not apply in several states where targets are tailored to individual utilities.).

- The target must be statewide for all utilities falling under the jurisdiction of the regulatory commission.
- There must be consequences for failing to meet the target.
- The target must extend at least three years.

Table 7 lists shows a list of state with an EERS as defined by each aforementioned organization.

Table7. States with an EERS in place as of January 2014

State	ACEEE	NREL	LBNL	State	ACEEE	NREL	LBNL
Arizona	●	●	●	Missouri			●
Arkansas	●	●		Nevada	●		
California	●	●	●	New Mexico	●	●	●
Colorado	●	●	●	New York	●	●	●
Connecticut	●			North Carolina	●		
Hawaii	●	●	●	Ohio	●	●	●
Illinois	●	●	●	Oregon	●	●	
Indiana	●	●	●	Pennsylvania	●	●	●
Iowa	●	●		Rhode Island	●	●	
Maine	●	●		Texas	●	●	●
Maryland	●	●	●	Vermont	●	●	
Massachusetts	●	●		Washington	●	●	
Michigan	●	●	●	Wisconsin	●	●	
Minnesota	●	●	●	Total	25	23	15

Note: Based on ACEEE's definition, as of April 2014, twenty-five states have EERS policies in place, as the Indiana EERS policy was rolled back ([4]-[5]).
Source: ACEEE ([6])

2.2.3. EERS Key Design Features

The key design features of an EERS include the following: authorities for creation and implementation; target type; target stringency; responsible entities and covered load; eligible savings measures; cost recovery; cost containment; incentives, penalties, and decoupling; and evaluation, measurement, and verification of savings ([11]). While details for each key design element are out of the scope of this report, we here briefly discuss various target types determined by state.

Target Type

Savings targets determined by states differ in the following aspects:

- *First*, targets can be specified in either "incremental" or "annual" terms. "Incremental savings" refers to the reduction in energy use in a given year contributed from energy efficiency measures installed in that year, while "annual savings" counts the reduction in energy use resulting from energy efficiency measures installed in prior years that continue to provide savings, in addition to the reduction resulting from new efficiency measures installed in that year ([11]).
- *Second*, targets can be specified in absolute terms (e.g., XX GWh/yr) or in relative terms (e.g., savings equivalent to Y% of 20ZZ electricity consumption) ([11]). There are two types of bases from which the relative (percentage) reduction is calculated: *fixed* (using energy consumption in a fixed period to calculate the required level of savings) and *rolling* (using energy consumption in a moving period that changes with the compliance year) ([11]).

Table 8 shows state EERS target type, units, basis and nominal targets in the final year, and Table 9 summarizes key design elements to determine savings targets.

Table8. State EERS Savings Target Specifications

	Unit	Basis Type	Basis	Nominal Target as Specified in Final Year of Policy[a]
Target Type: Incremental Savings				
AR	%	Fixed	2010 Consumption	0.75% (2014)
CA	GWh	N/A	-	1,968 GWh (2014)
CO	GWh	N/A	-	549 GWh (2020)
MA	GWh	N/A	-	1,275 GWh (2015)
ME	GWh	N/A	-	139 GWh (2016)
OR	GWh	N/A	-	491 GWh (2014)
RI	GWh	N/A	-	189 GWh (2014)
IA	%	Rolling	Avg. of Previous 3 Years' Consumption	1.3% (2013)
IL	%	Rolling	Previous Year's Consumption	2.0% (2015-)[b]
MI	%	Rolling	Previous Year's Consumption	1.0% (2012-)[b]
MN	%	Rolling	Avg. of Previous 3 Years' weather normalized consumption	1.5% (2010-)[b]
TX	%[d]	Rolling	Avg. of Previous 5 Year's Load Growth	30% (2010-)[b]
Target Type: Annual Savings				
MD[c]	%	Fixed	2007 Per Capita Electricity Consumption	15% (2015)
NM	%	Fixed	2005 Electricity Consumption	8.0% (2020)
NY	%	Fixed	2015 Electricity Consumption (forecasted)	15.0% (2015)
PA	%	Fixed	June 2009 - May 2010 Consumption	5.3% (2016)
HI	GWh	N/A	-	4,300 GWh (2030)
VT	GWh	N/A	-	320 GWh (2014)
WA	GWh	N/A	-	8,745 GWh (2021)
WI	GWh	N/A	-	1,816 GWh (2014)
AZ	%	Rolling	Previous Year's Consumption	22.0% (2020)
OH	%	Rolling	Avg. of Previous 3 Years' Consumption	22.0% (2025)

[a] Given that the nominal specifications of the EERS targets are listed and the final year of the policy varies, these targets cannot be directly compared across states.
[b] In these states targets apply to the specified year and all years following.
[c] Maryland targets are specified as a percent of per capita electricity consumption.
[d] Texas targets are specified as a percent of electricity demand growth.
Source: NREL ([11])

Table9. Key Elements to Design Target Specification

Design Element		Definition	Key Effects, Implications, and Considerations	State Examples
Target Type	Incremental	Savings in a given year resulting from energy efficiency measures installed in that year	▪ Compliance assessment solely requires measurement of savings from efficiency measures installed in the given compliance year (i.e., focus on 1st-year savings) ▪ May incentivize lower cost measures that provide only short-term savings	CA, MA, MN
	Annual	Savings in a given year resulting from energy efficiency measures installed in that year and measures installed in prior years (as defined by the policy) that continue to provide savings	▪ Compliance assessment requires measurement of savings from efficiency measures installed in the compliance year and previous years (i.e., lifetime savings) ▪ Incentivizes measures that provide both near- and long-term savings ▪ Enhances certainty of achieving long-term savings goals ▪ Increases complexity of EM&V and accounting due to erosion of savings of older measures	AZ, MD, NY
Basis Type	Fixed	The *static* quantity, typically consumption in a fixed year, by which a percentage target is multiplied to determine an absolute amount of required savings	▪ Provides certainty in the amount of required savings ▪ Amount of required savings is unresponsive to changes in market conditions	MD, NY, PA
	Rolling	The dynamic quantity, often consumption in the previous year, by which a percentage target is multiplied to determine an absolute amount of required savings	▪ May create uncertainty in the amount of required savings ▪ Amount of required savings adjusts to changes in market conditions	AZ, IL, OH

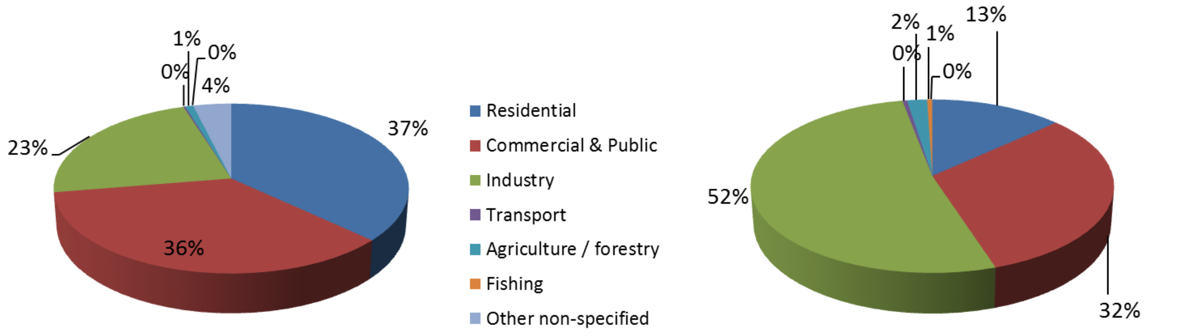
Source: NREL ([11])

Chapter 3 Energy Efficiency Measures and Databases

3.1 Sectoral Energy Consumption

3.1.1. Energy Consumption by Sector in the U.S. and Korea

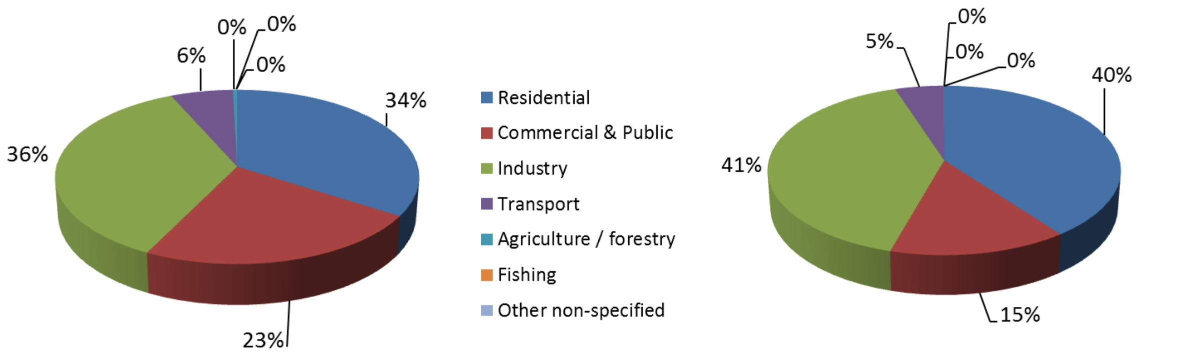
In the U.S., the residential, commercial, and industrial sectors account for 37%, 36%, and 23%, respectively, of final energy consumption in electricity, while in Korea each sector represents 13%, 32%, and 52%, respectively (see Figure 3, [12]). For natural gas, in the U.S., the residential, commercial, and industrial sectors account for 34%, 23%, and 36%, respectively, of final energy consumption, while in Korea each sector represents 40%, 15%, and 41%, respectively (see Figure 4, [12]).



U.S. **Korea**

Source: IEA ([12])

Figure 3. Electricity Consumption by Sector in the U.S. and Korea in 2012



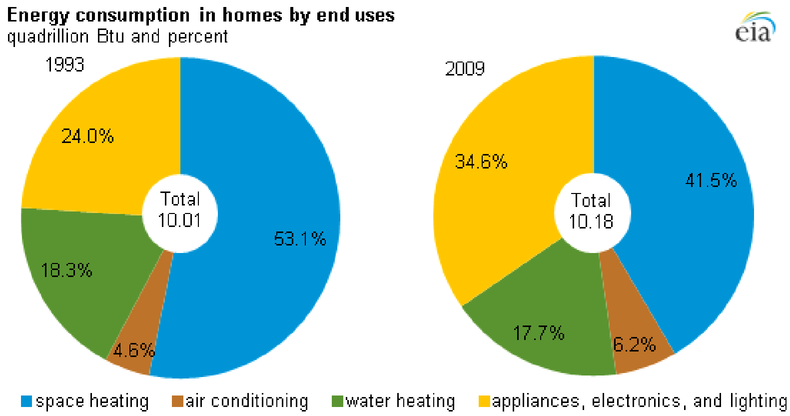
U.S. **Korea**

Source: IEA ([12])

Figure 4. Natural Gas Consumption by Sector in the U.S. and Korea in 2012

3.1.2. Sectoral Energy Consumption by End Use

According to the U.S. Residential Energy Consumption Survey (RECS) results for 1993 and 2009, space heating, water heating, appliances, electronics and lighting account for more than 90% of energy consumption in U.S. households (see. Figure 5, [13]).

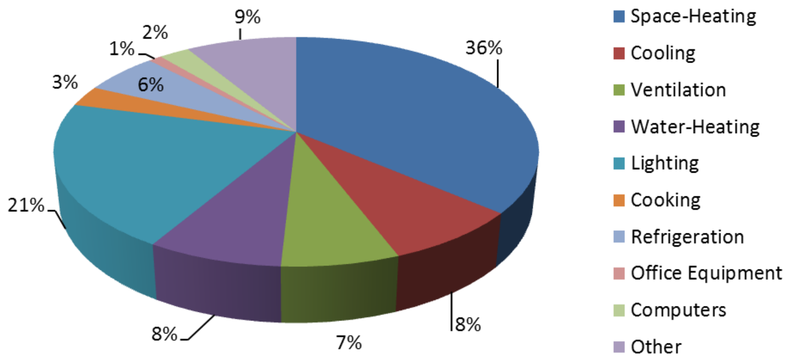


Source: US EIA ([13])

Note: This is to show the consumption trends changed over time. The RECS results were available for 1993, 1997, 2001, 2005, and 2009 at the time of study.

Figure 5. Energy Consumption in U.S. Homes by End Uses in 1993 and 2009

The US EIA has also been periodically conducting commercial building energy consumption survey (CBECS) since 1979. The US EIA has recently released the 2012 CBECS preliminary results ([17]), but detailed information on energy consumption in commercial buildings is expected to be released during 2015. According to the 2003 CBECS results, space-heating and lighting represent about 60% of fuel consumption for all buildings (see Figure 6, [18]).



Source: US EIA ([18])

Figure 6. Major Fuel Consumption by End-Use for All Buildings in 2003

According the Annual Energy Outlook (AEO) 2014 early release report, space heating & cooling, water heating, lighting and refrigeration dominate energy consumption in both sectors. They are estimated to account for about 65% of the total energy consumption in the residential sector and 50% in the commercial sector (see Figure 7 and 8, [20]).

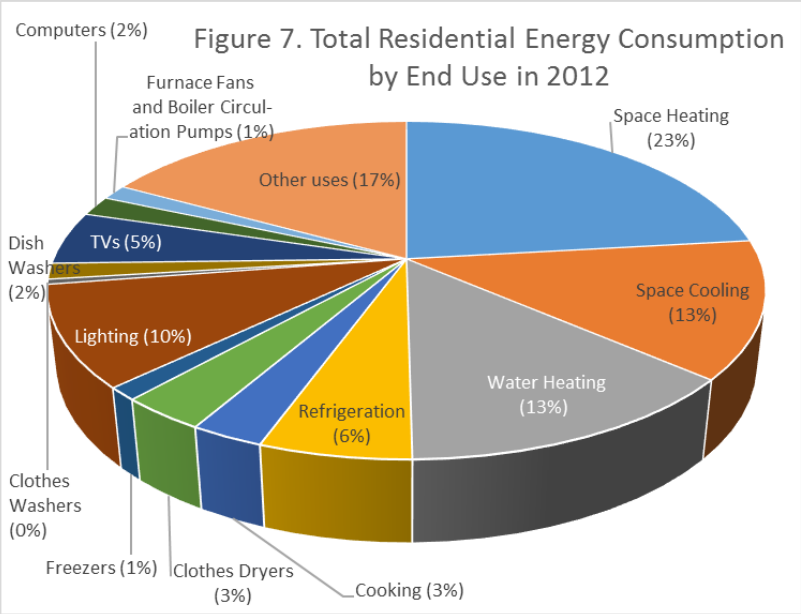


Figure 7. Total Residential Energy Consumption by End Use in 2012
Source: US EIA ([20])

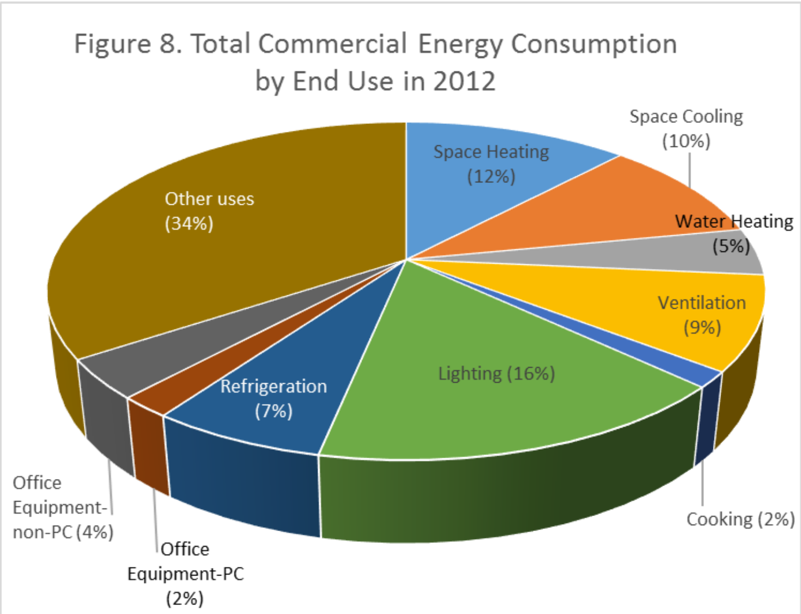
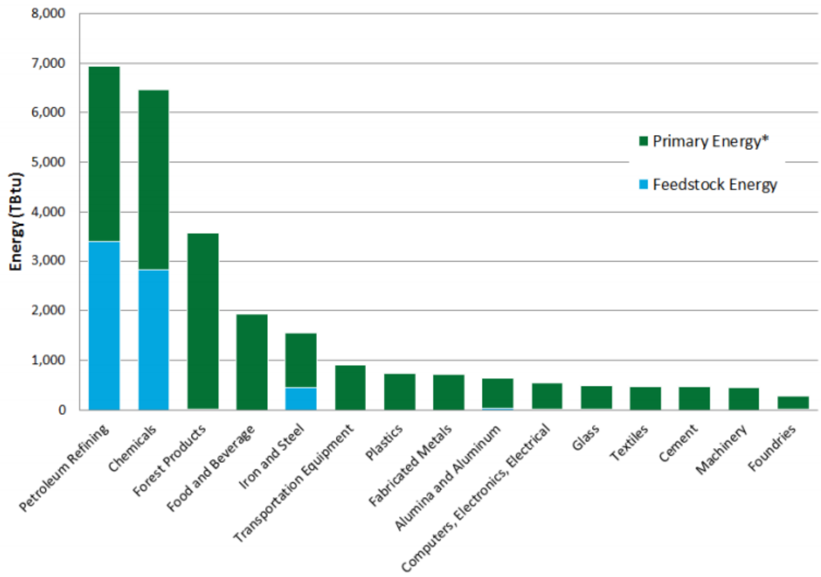


Figure 8. Total Commercial Energy Consumption by End Use in 2012
Source: US EIA ([20])

Manufacturing makes up about 85% of total energy consumption in the industrial sector with the remaining 15% consumed by the non-manufacturing sector, which includes agriculture, mining, and construction ([23]). Figure 9 shows total 2006 energy consumption by sub-sector, including primary and feedstock energy. Table 10 also shows that chemicals, forest products, petroleum refining, food and beverage, and iron & steel subsectors account for the majority of energy consumption in the industrial sector.



Note: Primary energy use has been adjusted to exclude the energy value of byproduct fuels derived from feedstock energy sources (e.g., waste gas from LPG feedstock in the chemicals sector); this exclusion avoids double counting feedstock energy. For petroleum refining only, there is no adjustment to this case, as the feedstock energy includes energy feedstock used for the production of non-energy products, i.e., it does not include energy feedstock that is converted to other energy products.
Source: US EIA ([23])

Figure 9. U.S. Manufacturing Total Primary and Feedstock Energy[5]

Table10. Snapshot of Selected Industrial Sectors: Energy Use and Rank within U.S. Manufacturing

Category	Chemicals	Forest Products	Petroleum Refining	Food and Beverage	Iron and Steel
Total primary energy	1	2	3	4	5
Offsite Losses	1	2	8	3	4
Onsite Energy	2	3	1	4	5
Onsite Losses	2	1	3	4	5
Steam Gen. and Dist.	2	1	3	4	5
Electricity Gen.	1	2	3	5	4
Process Energy	2	1	3	4	5
Non-process Energy	2	1	11	4	9
Feedstock energy	2	6	1	9	3
Total Primary and Feedstock Energy*	2	3	1	4	5
GHG Emissions (Total, Onsite)	1, 2	3, 3	2, 1	4,4	5, 6

*When total primary energy and feedstock energy are summed, the energy value of byproduct fuels derived from feedstock energy sources is excluded to avoid double counting of feedstock energy.
** BLUE refers to losses.
Source: ORNL ([23])

[5] There are two types of energy use in the manufacturing sector [22]:

- Energy consumed for fuel – all energy used for heat, power, and electricity generation, regardless of where the energy was produced.
- Energy consumed for feedstock (sometimes referred to as nonfuel) – energy used as a raw material for purposes other than heat, power, and electricity generation

In addition, electricity and gas are used throughout the industrial sector for pumps, compressors, lighting, heating and cooling, ventilation, etc. It is important to focus on cross-cutting industrial systems. For example, in two selected industries—petrochemical and petroleum refining, steam systems and motor systems (including pumps, fans and compressed air systems) represent, respectively, more than 30% of all onsite energy use and nearly 60% of total electricity use (see Table 11).[6]

Table11. Energy Consumption of Cross-cutting Systems in Two Industries

Category	Petrochemical	Petroleum Refining
Steam Systems	~37% of all onsite energy use	~30% of all onsite energy use
Process Heating	~30% of all fuel is used in fired heaters	Over 60% of all fuel used in furnaces and boilers
Motor Systems	~57% of the total electricity use	Over 80% of total electricity use
Pumps	15%	48%
Fans	7%	7%
Compressed Air Systems	16%	12%
Other	19%	13%

Source: LBNL ([35], [36])

3.2 Energy Efficiency Measures

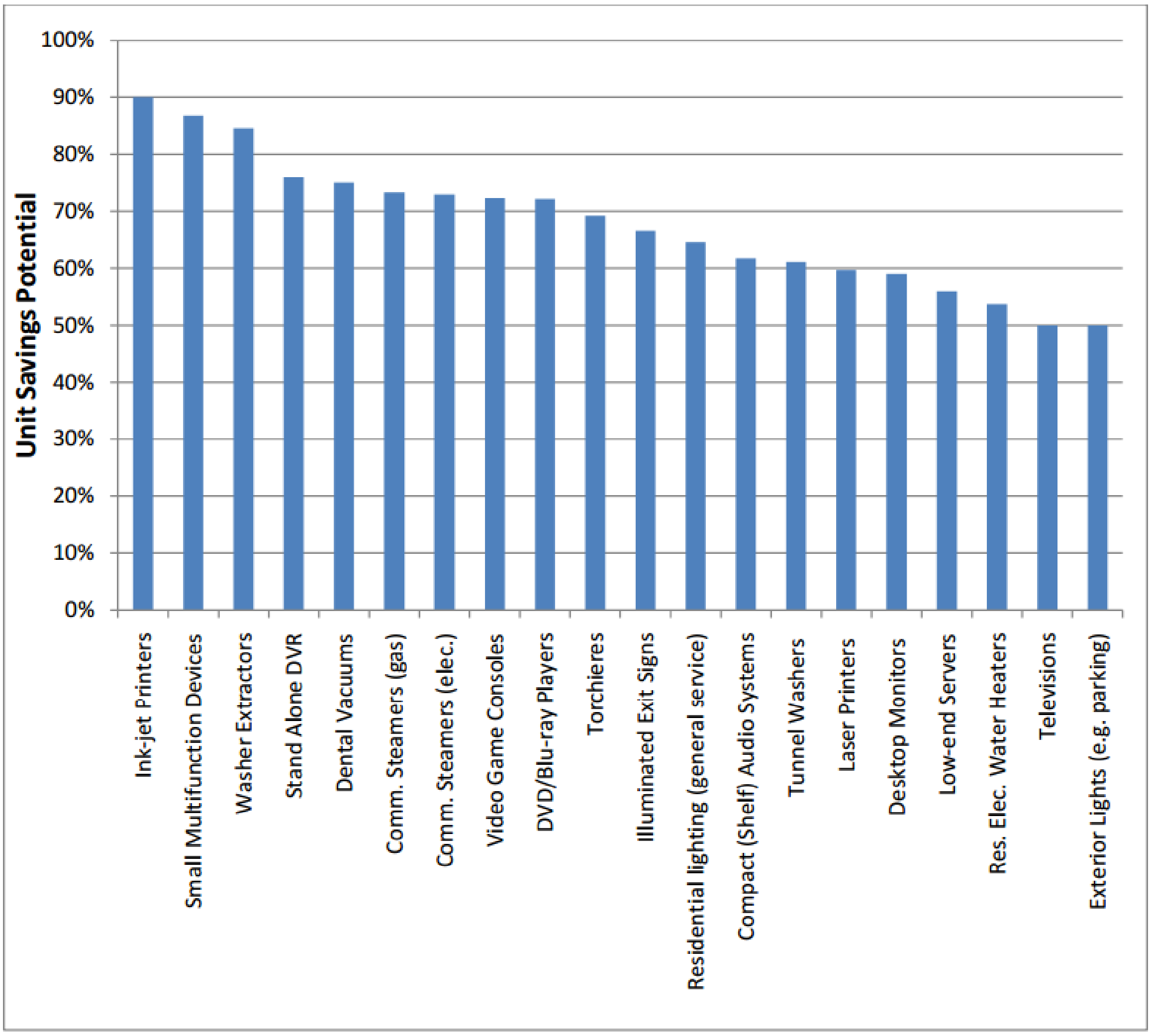
Energy efficiency measures in this report refer to the specific technologies (e.g., efficient lighting fixture) and practices (e.g., duct sealing) that are used to achieve energy savings ([9]).

3.2.1. Residential Sector

In 2011, LBNL identified energy efficiency improvement options for appliances and equipment in the residential, commercial, and (in some cases) industrial sectors (over 150 types of product categories), and ranked the best practices by national energy saving potential ([14]). The LBNL study found that while many applications offer large per-unit savings, several product categories (including, lighting, electric water heaters, central air conditioners, general pumps, gas furnaces, and televisions) are estimated to account for the majority of national energy-saving potential, which indicates that the product group has in the market would be more important than per-unit savings potential of a single product, e.g., ink-jet printers, to EE programs. (see Figure 10 and 11, [14]). In addition, there are cross-cutting technologies that can be applicable to a range of appliances and equipment across sectors. Some examples include the following: advanced lighting technologies, including LEDs, OLEDs, sensors and controls in many applications; power management strategies (especially in electronics, heat pumps, variable-speed drives, pumps, and fans), and brushless direct current (DC) permanent magnet motors ([14]). Table 12 summarizes examples of

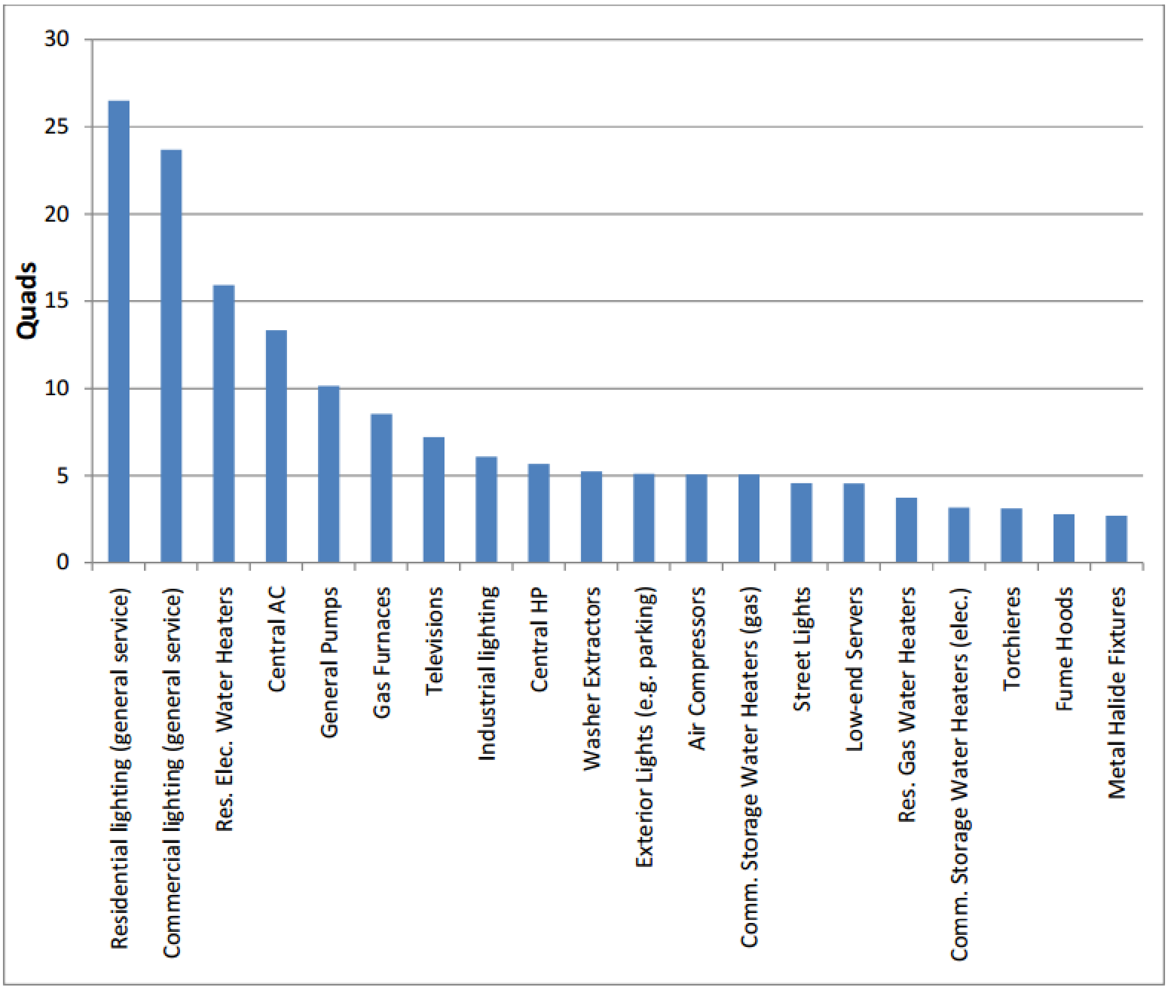
[6] In petroleum refining, motor systems use over 80% of total electricity consumed.

energy efficiency improvement options in the residential sector and Table 13 shows specific technology options that can improve room AC efficiency.



Source: LBNL ([14])

Figure 10. Energy Top 20 End-Uses in terms of Per-unit Energy-Saving Potential



Source: LBNL ([14])

Figure 11. Energy Top 20 End-Uses in terms of 30-year Energy-Saving Potential Nationwide

Table12. Examples of Energy Efficiency Improvement Options in Residential Sector

	Baseline Technology	Efficiency Improvement Options
Room Air Conditioners	-	Improved heat exchangers; improved motor efficiency; improved expansion valves; variable-speed compressors
Central Air Conditioners and Heat Pumps	-	Improved heat exchangers; variable-speed compressors with brushless DC permanent-magnet motors; variable-speed air handler/furnace fan
Clothes Dryers (residential)	Electric clothes dryers	Heat-pump clothes dryers where the air typically moves in a closed loop
Clothes Washers (residential)	-	Utilizing nylon beads, efficient speed control (by variable-speed drives with brushless DC motors), efficient water recirculation, improved sensors and automatic controls
Fans	Shaded-pole motors, split-capacity motors	Brushless DC motor, efficient blade design, ceiling fan light kits with efficient lights
Lighting	Incandescent, CFL	LED
Freezers	-	Improved heat exchangers; improved compressor efficiency; variable-speed compressors; adaptive defrost and anti-sweat heaters; DC fan motors; and improved gasket seals
Refrigerators	-	Enlarged the heat exchange area, efficient compressors, variable-speed compressors, DC fan motors
Boilers	-	Condensing boilers
Televisions	CRTs, CCFL backlit LCDs	LED backlit LCDs, OLEDs
Water Heaters	・Electric resistance storage water heaters (EF ~0.9) ・Gas water heaters (EF ~0.6)	・Heat-pump water heaters for electric heating (EF ~2.35) ・Condensing water heaters for gas heating (EF ~0.9)

Source: LBNL ([14]-[15])

Table13. Examples of Efficiency Improvement Options for Room Air Conditioners

Option	Description	% improvement from base case
Efficient Heat Exchanger	high efficiency micro-channel heat exchangers, larger sized heat exchangers	9.1%-28.6%
Efficient Compressors	two-stage rotary compressors, high efficiency scroll compressors with DC motors	6.5%-18.7%
Inverter/Variable Speed	AC, AC/DC or DC inverter driven compressors	20%-24.8%
Expansion Valve	Thermostatic and electronic expansion valves	5%-8.8%
Crankcase Heating	Reduced crankcase heating power and duration	9.8%-10.7%
Standby Load	Reduced standby loads	2.2%
Total/Cumulative		60%-72%

Note: The base case is defined as a split fixed-speed room AC model and the savings figures presented here are representative of conditions in Europe.
Source: LBNL ([16])

3.2.2. Commercial Sector

Table 14 shows some examples of energy efficiency improvement options for end uses in commercial buildings. Table 15 shows the "lost-opportunity"[7] and retrofit measures identified by the NWPCC as being cost-effective and achievable by 2025 ([19]).

[7] Lot-opportunity resources refer to measures that must be undertaken when buildings are constructed or remodeled and when new or replacement equipment is purchased ([19]).

Table14. Examples of Efficiency Improvement Options in Commercial Buildings

	Baseline Technology	Efficiency Improvement Options
Commercial Unitary ACs and Heating Equipment	-	Variable-speed compressors (or optimized compressors for a given capacity); efficient variable-speed blowers and fans; improved heat exchangers (e.g., brazed plate and micro-channel); optimized refrigerants; variable-speed drives with brushless DC permanent magnet motors; advanced evaporative coolers
Clothes Dryers (commercial)	-	Pre-heating the inlet air and providing better modulation controls (Large commercial dryers are already relatively efficient.)
Clothes Washers	Tunnel washers	Switching to a cold-water wash cycle that uses either a specially designed detergent or an advanced ozone cleaning system; Utilizing a low-temperature wash
Computing & Office Equipment		Proper power management in both of operating modes and of the computer microchips; advanced disk drives (e.g., solid state drives) and power supplies; virtualization for networked servers; proper management in the fuser roller temperature of the laser imaging device for large, multifunction devices and high-volume office equipment; advanced toners that works at low temperatures; uninterruptable power supplies (UPSs)
Illuminated Exit Signs	LED, CFL	Electroluminescent exit signs (or light-emitting capacitor (LEC) exit signs); photo-luminescent and tritium-based exit signs
Lighting	T12 fluorescent tubes	T5 or T8 tubes; LEDs; high-efficiency fixtures (e.g., reflective coatings, low obscuration); sensors and controls that provide dimming, multi-level lighting, and on/off capabilities; high-intensity discharge (HID) and low-pressure sodium (LPS) lamps; photovoltaic (PV)-integrated DC lighting

Source: PNNL ([19])

Table15. “Lost-Opportunity” and Retrofit Measures in Commercial Sector

	Measure	Cost-Effective Savings Potential (MWa* in 2025)	Average Levelized Cost ($/kWh)	Benefit/ Cost Ratio
Lost Oppo-rtunity	Efficient AC/DC Power Converters	156	0.015	2.7
	Integrated Building Design	152	0.023	4.8
	Lighting Equipment	101	0.003	12.1
	Packaged Refrigeration Equipment	68	0.019	1.9
	Low-Pressure Distribution	47	0.027	1.6
	Skylight Day Lighting	34	0.034	1.6
	Premium Fume Hood	16	0.037	1.0
	Municipal Sewage Treatment	11	0.014	2.4
	Roof Insulation	12	0.015	2.1
	Premium HVAC Equipment	9	0.043	1.2
	Electrically Commutated Fan Motors	9	0.024	1.8
	Controls Commissioning	9	0.037	1.1
	Variable Speed Chillers	4	0.031	1.6
	High-Performance Glass	6	0.030	1.4
	Perimeter Day Lighting	1	0.063	0.9
Retrofit	Lighting Equipment	114	0.018	2.2
	Small HVAC Optimization and Repair	75	0.032	1.4
	Network Personal Computer Power Mgt.	61	0.028	1.3
	LED Exit Signs	36	0.023	1.6
	Large HVAC Optimization and Repair	38	0.037	1.2
	Grocery Refrigeration Upgrade	34	0.019	1.9
	Office Plug Load Sensor	13	0.031	1.2
	High-Performance Glass	9	0.029	1.3
	Adjustable Speed Drives	3	0.043	1.1
	Municipal Water Supply	25	0.033	1.2
	Municipal Sewage Treatment	37	0.014	2.4
	LED Traffic Lights	8	0.019	1.8

*MWa (Average Megawatts)
Source: PNNL ([19])

Table 16 shows examples of cross-cutting energy-saving design options for appliances and equipment used in residential, commercial and industrial sectors.

Table16. Cross-Cutting Energy-Saving Design Options

Approach	Products to which strategy is applicable	Remarks	Energy-saving potential (approximate)
Electronic lighting (fluorescent and LED) replace conventional incandescent lighting	Many; replacing incandescent bulbs, primarily in the residential and commercial sectors	Only the residential sector remains dominantly incandescent. Although LED and CFL efficacies currently are similar, LED efficacies are expected to increase faster and have a higher technical potential to do so.	~75% (commercial) ~60% (residential)
Heat pump technology (air and ground source) replace standard electric and gas heating	Water heaters, space heating, and clothes dryers	Uses reverse-refrigeration cycle, efficiency can be enhanced by use of CO_2 as refrigerant, absorption cycle use for gas-heat pump	~50% - 70+% (water heaters) ~25% – 50% (dryers) ~30% – 40% (space heating)
Controls I: Power Management	Lighting, consumer electronics; heating, ventilation, and air conditioning (HVAC) systems; many appliances	Impact appears large, but involves large uncertainties; depends on the application and user behavior. Included are on/off controls, multilevel output, and output modulation. For electronic devices, includes more intelligent sleep modes and power scaling for chips.	~50% – 70% (TVs) ~20% – 50% (lighting) ~5% – 30% (other electronics)

Controls II: Variable-Speed Drives (VSDs)	Compressors, pumps, blowers, dishwashers, refrigerators, and air conditioning systems	Advantageous only for applications that involve variable load conditions.	~30%-50%
Controls III: Using multiple smaller components or devices to replace one larger one	Transformers, power supplies, compressors, and pumps	Applies to power conversion technologies and related systems that, at low loads, operate at low efficiencies. Turn off unneeded systems and operate the others at conditions closer to optimal efficiency	~20%-50%
Efficient motors (many approaches)	Any product that has a motor (from major consumer appliances to industrial machinery)	Different efficiency strategies may apply to different applications; in general will have greater impacts on smaller motors.	~10%-40%
Improved power supplies	Consumer electronics	-	~2%-5%
LED*, OLED	Electronic displays (portable electronics, TVs); lighting	OLED is currently used primarily for small displays.	~50-90%

*In addition to OLED, authors have added LED to the emerging technology as LED technology has been rapidly evolving in terms of efficiency and cost.
Source: LBNL ([14])

3.2.3. Industrial Sector

For energy efficiency measures in the industrial sector, this report discusses industrial equipment that is applicable in a wide range of industries, e.g., steam systems and motor systems, as well as industry-specific measures for selected industries.

A. Motors

Although single-speed induction motors dominate the U.S. market, brushless DC permanent motors with an efficient core (e.g., laminated amorphous metal) and low-resistance conductors, and low-friction bearings are considered to be one of the best available technologies for energy efficiency improvement ([14]-[15]). Variable-speed motors that often use efficient brushless DC motors can offer even larger savings because they respond to load conditions so as to reduce energy demand in the system being driven by the motors ([14]-[15]). Table 17 shows efficiency improvement potential in the aforementioned best available technology, compared to the conventional motors.

Table17. Efficiency Improvement Potential in Motors

Type	Business-as-usual (Efficiency %)	Best available technology (Efficiency %)
0.75-7.5 kW	74%-84%	89%
7.5-75 kW	87%-91%	94%
> 75 kW	93%-95%	96%

Source: LBNL ([15])

B. Pumps

Pumps are estimated to account for about 27% of industrial energy use ([14]). While pumping efficiency depends on many factors, for many applications, using variable-speed drives (VSDs) to operate pumps offers large energy savings, improved performance, and reliability, along with reduced life-cycle costs and short payback periods (less than a few years) ([14]). The LBNL study assumed that the best-on-market pumps available at the time of the study achieve 25% savings and the efficiency can be further technically improved by 25% for all applications of pumps ([14]).

C. Distribution Transformers

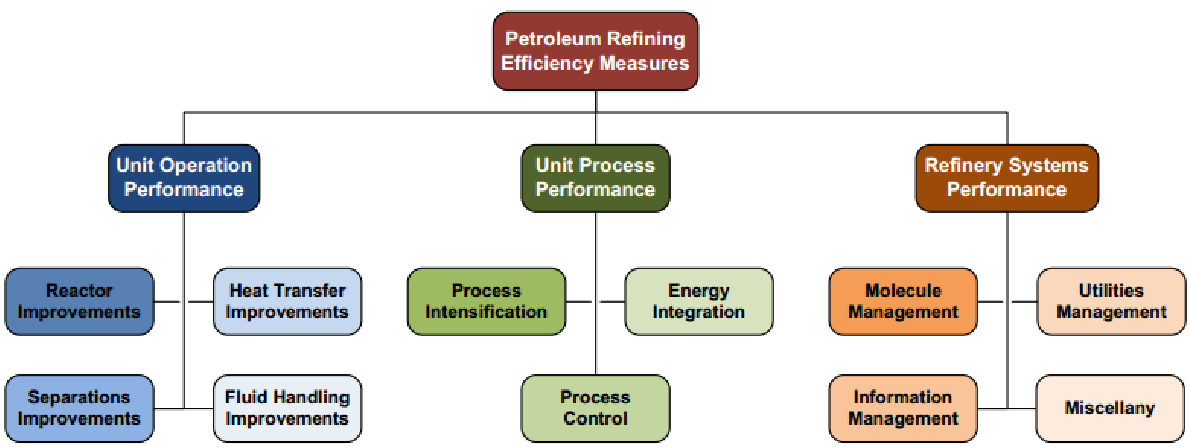
Distribution transformer efficiency can be improved by using an amorphous metal core and hexaformer geometries that reduce efficiency losses by up to 30%, compared to conventional transformers ([15]). In addition, smaller transformers with a centralized control, which replaces a single transformer, can improve overall efficiency of the system, e.g., hexaformer transformers with this type of control reduce energy losses by about 50% ([15]).

D. Steam Generation and Distribution

Steam is used throughout many industries. For example, steam systems represent more than 30% of all onsite energy use in petrochemical and petroleum refining sectors ([35], [36]). Steam can be generated by boilers, waste heat recovery from processes and cogeneration with electricity ([35]). Industry uses steam for a wide range of purposes such as process heating, drying, concentrating, steam cracking, distillation, and to drive compressors, for example ([35]). While its use varies by industry, efficiency improvements in steam generation, distribution and end-use are possible. The U.S. DOE estimated the overall potential for energy savings in the U.S. chemical and petroleum refining industries, respectively, at over 12% ([35], [36]).

D. Petroleum Refining Sector

The petroleum refining sector is the largest consumer of fuel in U.S. manufacturing and has the largest process heating energy demand of all manufacturing sectors ([23]). LBNL analyzed efficiency measures for all twelve of the unit processes in the petroleum refining sector to estimate energy-usage abatement curves. Figure 12 shows the efficiency measures categorized in the study, and Table 18 shows examples of efficiency measures for selected individual unit processes.



Source: LBNL ([24])

Figure 12. Efficiency Measures Hierarchy in Petroleum Refining Sector

Table18. Examples of Efficiency Measures for Selected Individual Unit Processes

Unit Process	Energy-Efficiency Measures / Technologies	Combined Fuel and Electricity Savings (PJ)	Cost of Conserved Fuel (US$/GJ-saved)
CDU	Reduce stand-by boiler requirements	3.3	-$1.90
	Reduce hot rundown/storage between ACU&VDU	3.6	-$0.47
	Reduce boiler blow down/water treatment	25.7	$0.47
	Add steam recycle with steam ejector to VDU	35.8	$0.75
	Install vacuum pump to replace overhead steam ejectors	129.3	$3.31
CKU	Recover Blowdown Steam	0.4	-$0.47
	Install SRU Waste Heat Boiler	1.3	$0.00
	Reduce Boiler Blowdown/Water Treatment	2.9	$0.47
	Integrate GPU w/ISBL Units	6.5	$1.97
	Integrate AGR w/ISBL Units	5.1	$2.36
CCU	Recover Blowdown Steam	0.2	-$0.47
	Reduce Boiler Blowdown/Water Treatment	1.2	$0.47
	Integrate GPU w/ISBL Units	26.2	$1.97
	Increase AGR Solvent Concentration	1.5	$2.37
	Replace Steam Drives w/Elec on Air Compressors	7.7	$4.11

ACU (Atmospheric Crude Unit); AGR (Acid Gas Removal); CCU (Catalytic Cracking Unit); CDU (Crude Distillation Unit); CKU (Coking Unit); GPU (Gas Processing Unit); ISBL (Inside Battery Limits); SRU (Sulfur Recovery Unit); VDU (Vacuum Distillation Unit)
Source: LBNL ([24])

E. Iron and Steel Sector

Although energy use in the U.S. steel industry has been declining, it is one of the largest energy consuming industries in the manufacturing sector, accounting for roughly 6% of the total energy consumed in manufacturing ([22]). LBNL has been conducting several iron and steel sector studies that assess energy savings and costs of energy efficient technologies and measures. Table 18 lists selected examples from the 77 energy efficient technologies analyzed in Karali et al. 2013.

Table19. Examples of Efficient Technologies and Measures in Iron and Steel Sector

Steelmaking Electric Arc Furnace -
Improved process control (neural network); Fluegas Monitoring and Control; Transformer efficiency - UHP transformers; Bottom Stirring / Stirring gas injection; Foamy slag; Oxy-fuel burners; DC-Arc furnace; FUCHS Shaft furnace; etc.
Secondary Casting -
Efficient ladle preheating; Proper sealing on ladle furnace preheating; Near net shape casting/thin slab casting (TSC); Use dry rolls in tunnel ovens for TSC
Secondary Hot Rolling -
Process control in hot strip mill; Recuperative burners; Insulation of furnaces; etc.
General Technologies -
Preventative Maintenance; Optimizing the steam system; Increase efficiency of boilers, etc.
Iron Ore Preparation (Sintering) -
Sinter plant heat recovery; Reduction of air leakages; Increasing bed depth, etc.
Coke Making -
Coal moisture control; Programmed heating - coke plant; Coke dry quenching, etc.
Iron Making (Blast Furnace)
Pulverized coal injection to 130 kg/thm; Top pressure recovery turbines (wet type); Recovery of blast furnace gas; Hot blast stove automation; Recuperator hot blast stove; etc.
Basic Oxygen Furnace
BOF gas + sensible heat recovery; Variable speed drive on ventilation fans
Integrated Casting
Efficient ladle preheating; Proper sealing on ladle furnace preheating; etc.
Integrated Hot Rolling
Hot charging; Recuperative burners; Insulation of furnaces; Ceramic wall in reheating furnace; Reduce losses from furnace door opening; etc.
Integrated Cold Rolling and Finishing
Heat recovery on the annealing line; Reduced steam use in the pickling line; etc.
General
Increase efficiency of boilers; Optimizing the air system; Variable speed drive: flue gas control, pumps, fans; etc.

Source: LBNL ([25])

F. Cement Sector

Energy consumption in the U.S. cement industry declined between 1970 and 2010, while production increased over that same time period ([26]). The industry is estimated to contribute approximately 4% of all industrial CO_2 emissions in the U.S. (equivalent to approx. 2% of total U.S. CO_2 emissions, [26]).

Table 20 shows a list of energy-efficient practices and technologies in cement production.

Table20. Examples of Efficient Technologies and Measures in Cement Sector

Raw Materials Preparation	
Efficient transport systems (dry process) Raw meal blending systems (dry process) Slurry blending and homogenization (wet process) Conversion to closed circuit wash mill (wet process) Advanced raw meal grinding (dry process)	Separate raw material grinding (dry process) Raw meal process control (dry process) High-efficiency classifiers/separators Fuel preparation: Roller mills
Clinker Production (Wet)	**Clinker Production (Dry)**
Energy management and process control Kiln combustion system improvements Mineralized clinker Indirect firing Oxygen enrichment Mixing air technology Seal replacement Kiln shell heat loss reduction Refractories Efficient kiln drives Conversion to modern grate cooler Optimize grate coolers Conversion to semi-dry kiln (slurry drier) Conversion to semi-wet kiln (filter press system) Conversion to pre-heater, pre-calciner kiln	Energy management and process control Kiln combustion system improvements Mineralized clinker Indirect firing Oxygen enrichment Mixing air technology Seal replacement Kiln shell heat loss reduction Preheater shell heat loss reduction Refractories Efficient kiln drives Conversion to modern grate cooler Optimize grate coolers Conversion to modern grate cooler Optimize grate coolers
Finish Grinding	
Energy management and process control Vertical roller mills Horizontal roller mills High-pressure roller presses – pre-grinding	High-pressure roller presses – finish grinding High efficiency classifiers Improved grinding media (ball mills)
General Measures	
Preventative maintenance (insulation, compressed air system, maintenance) High efficiency motors Optimization of compressed air systems	High efficiency fans Efficient lighting Efficient dust collectors
Product & Feedstock Changes	
High Alkali cement Blended Cements Limestone Portland cement Reducing fineness of cement for selected uses Use of steel slag in kiln (CemStar®)	Use of fly ash and blast furnace slag in kiln Use of cement kiln dust in kiln Use of calcareous oil shale in kiln Lower lime saturation factor

Note that not all measures in this table can apply to all plants.
Source: LBNL ([26])

G. Textile Sector

Although the textile sector is not considered an energy-intensive industry, it consists of a large number of plants that collectively consume a significant amount of energy ([27]). In the U.S., the textile industry accounts for less than 2% of the total manufacturing final energy use in 2010 ([27]). Specifically, process heating and motor-driven systems are assessed to account for 76% of final energy use in the U.S. textile industry ([27]). Table 21 shows examples of energy efficiency measures for five major sub-sectors (i.e., Spinning, Weaving, Wet-processing, Worsted fabric manufacturing, and Carpet manufacturing) in the textile industry.

Table21. Examples of Efficient Technologies and Measures in Textile Sector

Subsector	EE Measures	Estimated Electricity Savings	Estimated Fuel Savings
Spinning	Installation of electronic roving end-break stop-motion detectors instead of pneumatic systems	3.2 MWh/ year/ machine	-
	Replacement of lighter spindles in place of conventional spindles in ring frames	23 MWh/ year/ ring frame	-
	Optimization of ring diameters with respect to yarn count in ring frames	10% of ring frame energy use	-
Spinning/ Weaving	Replacement of nozzles with energy-efficient mist nozzles in yarn conditioning room	31MWh/ year/ humidification plant	-
	Installation of variable frequency drives (VFD) for washer pump motors in humidification plants	20 MWh/ year/ humidification plant	-
Wet-processing	Preparatory Process - Combined preparatory treatments in wet processing, such as washing, desizing, and scoring	-	up to 80% of preparatory
	Preparatory Process - Use of counter-flow current for washing process	-	41% - 62% of washing energy use
	Dyeing and Printing Process - Equipment optimization in jet dyeing machines	increased 0.07 - 0.12 kWh/kg fabric	1.8 - 2.4 kg steam /kg fabric
	Dyeing and Printing Process - Heat insulation of high temperature/ high pressure dyeing machines	-	210 - 280 GJ/ year/plant
	Drying and Finishing Process - Introduce mechanical de-watering or contact drying before dryer/stenters	-	13% - 50% of stenter energy use
	Drying and Finishing Process - Install heat recovery equipment in dryer /stenters	-	30% of stenter energy use
	Optimize exhaust humidity in dryer /stenters	-	20 - 80% of stenter energy use

Source: LBNL ([28])

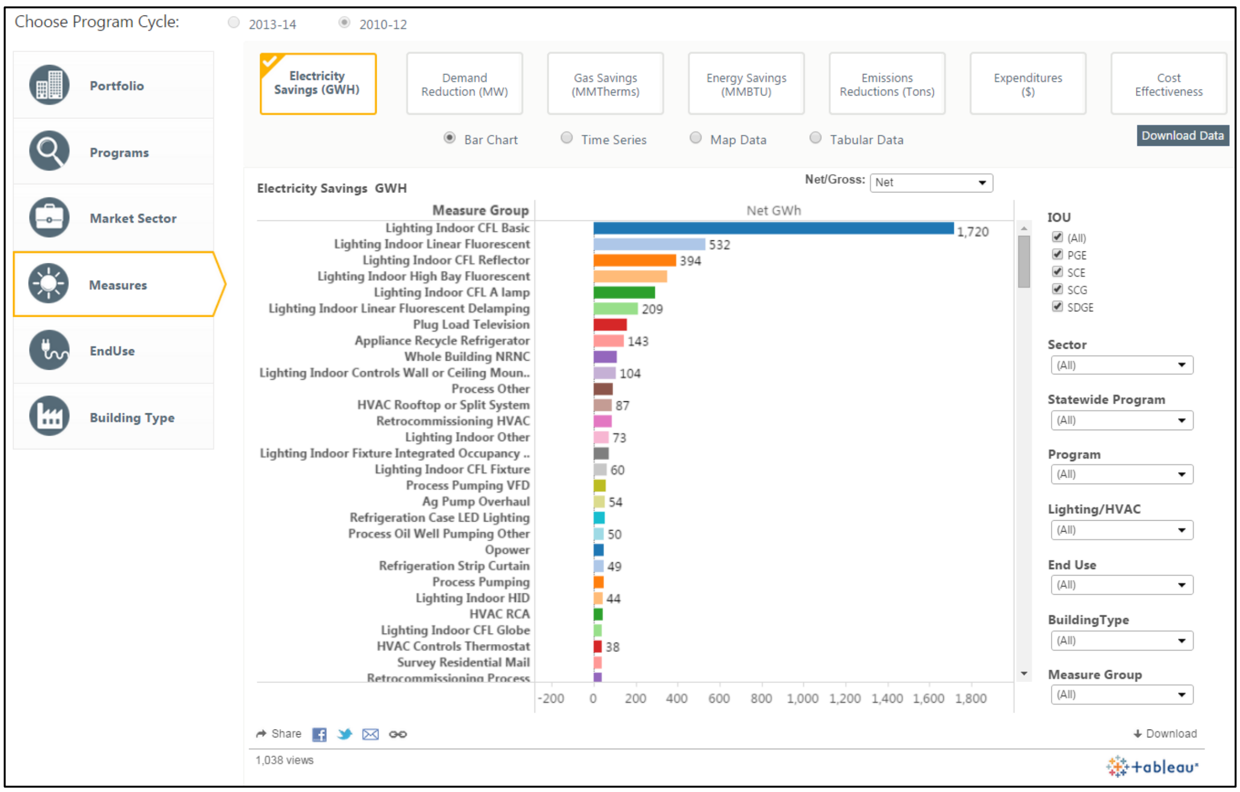
3.3 Sources for Energy Efficient Measures, Technologies and Practices

This study also explores existing energy efficiency measures databases designed to support energy efficiency policies and programs in the U.S. Following are some examples:

3.3.1. California – Database for Energy Efficient Resources (DEER)

http://www.deeresources.com/
http://eestats.cpuc.ca.gov/

California is one of the leading states in U.S. energy efficiency. The Database for Energy Efficient Resources (DEER) is a California Energy Commission (CEC) and California Public Utilities Commission (CPUC) sponsored database with information on energy efficient technologies and measures, designed for supporting program planners, regulatory reviewers and planners, utility and regulatory forecasters, researchers, and consultants in the energy efficiency field ([29]). The Energy Efficiency Portal provides information on electricity savings, demand reduction, gas savings, energy savings, emissions reductions, expenditures, and cost effectiveness by portfolio, programs, market sector, measures, end use, and building type (see Figure 13, Table 22, [30]).



Source: California Energy Efficiency Statistics (http://eestats.cpuc.ca.gov/)

Figure 13. A Screenshot of California's Energy Efficiency Portal

Table22. Summary of Key Elements in California's Energy Efficiency Portal

Category	Sub-Category	Data
IOU (Investor Owned Utilities)	PGE (Pacific Gas and Electric company); SCE (Southern California Edison), SCG (Southern California Gas Company); SDG&E (San Diego Gas & Electric)	▪ Electricity savings (GWh) ▪ Demand reduction (MW) ▪ Gas savings (MMTherms) ▪ Energy savings (MMBTU) ▪ Emissions reductions (CO_2 tons) ▪ Expenditures ($) ▪ Cost effectiveness
Implementors	IOU core/Statewide; Local Government Partnership; Third/Local Party Implementer	
Sector	Residential; Commercial; Industrial; Agriculture; Cross-Cutting	
Program Category	Continuous Energy Intensity Improvement; Emerging Technologies; Integrated Demand-Side Management; Market Transformation; New Construction; On-bill Financing; Retrofit; Zero Net Energy; etc.	
Programs	~70 Statewide Programs; ~240 Utility-specific Programs	
EE Measures	~240 Measure Groups	
End Use	~20 End Uses	
Buildings	~50 Building Types	

Source: Authors' work based on California Energy Efficiency Statistics (http://eestats.cpuc.ca.gov/)

3.3.2. Michigan –MI Energy Measures Database (MEMD)

http://www.michigan.gov/mpsc/0,4639,7-159-52495_55129---,00.html

The Michigan Energy Measures Database (MEMD), prepared by Morgan Marketing Partners, was designed to provide users with information on potential technologies and measures that could be used in energy efficiency programs for Michigan and was incorporated into the development of provider-specific Energy Optimization (EO) plans ([31]). The MEMD covers residential and commercial sectors, and provides base efficiency levels, proposed efficiency levels and incremental costs by efficiency measure.

Table23. Summary of Key Elements in Michigan's Energy Measures Database 2015

<table>
<tr><th>Category</th><th>Sub-Category</th><th>Data</th></tr>
<tr><td>Sector</td><td>Residential; Commercial; Multifamily Residential</td><td rowspan="4">▪ Base Efficiency Level
▪ Proposed Efficiency Level
▪ Assumed Hours of Operation
▪ 2015 Target
▪ Incremental Cost
▪ Installation Cost</td></tr>
<tr><td>EE Measure Groups</td><td>Appliances; Building Envelop; Commercial Kitchen and Refrigeration; Consumer Electronics; Controls; HVAC; Lighting; Motors, Pumps, and Drives; Water Heating

System Level: Central AC with electric furnace; Central AC with gas furnace; Central air source heat pump; Central dual fuel heat pump; etc.</td></tr>
<tr><td>Fuel Type</td><td>Electric; Gas; Combination</td></tr>
<tr><td>Buildings</td><td>Residential – Single Family, Multi Family
Commercial – Assembly, Big Box Retail; Biotech; Fast Food Restaurant; Full Service Restaurant; Grocery; High School; Large Office; Large Industrial; Primary School; Small Office; Small Retail</td></tr>
</table>

Source: MI Energy Measures Database ([31])

3.3.3. NREL – National Residential Efficiency Measures Database

http://www.nrel.gov/ap/retrofits/group_listing.cfm

The National Renewable Energy Laboratory (NREL) has developed a database of residential building retrofit measures and associated costs ([32]). Version 1 of the database was publicly released in February 2010, Version 2 and Version 3 were released in October 2010 and July 2012, respectively ([32]). Table 24 shows a summary of key elements of the database. Figure 18 shows a screenshot of the database in retrofit measures for light bulb.

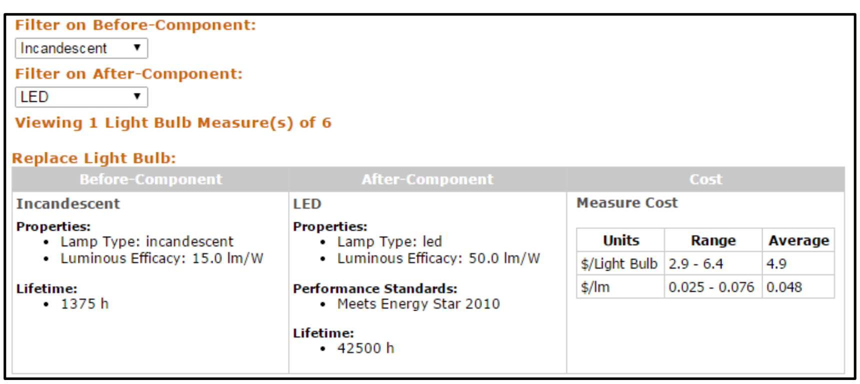
Table24. Summary of Key Elements in NREL's Residential Efficiency Measures Database

Category	Sub-Category		Data
Sector	Residential		▪ Components[a] ▪ Properties[b] ▪ Cost
EE Measure Types	Airflow	Air Leakage; Mechanical Ventilation	
	Ceilings/ Roofs	Finished Roof; Radiant Barrier; Roof Material; Unfinished Attic	
	Foundation/ Floors	Crawl Space; Slab; Unfinished Basement	
	Lighting	Flood Light; Light Bulb; Lighting Control; Torchiere	
	Major Appliances	Clothes Dryers; Clothes Washers; Dishwashers; Freezers; Refrigerators	
	Space Conditioning	Air Source Heat Pumps; Boilers; Ceiling Fans; Central ACs; Room ACs; Ducts; Furnace; Thermostat; etc.	
	Walls	Exterior Finish; Wall Sheathing; Wood Stud	
	Water Heating	Distribution; Showers; Sinks; Water Heaters	
	Windows & Doors	Doors (entry); Skylights; Windows	
	Miscellaneous	Water Coolers; Well Pumps	

Source: NREL ([32])

[a] Physical description of a particular building or system element including, but not limited to, any properties that affect the energy use of the home. A measure has a minimum of two components, before and after, but could have more than two.

[b] Description of the component: the properties can include lifetime, performance, etc.



Source: NREL (http://www.nrel.gov/ap/retrofits/group_listing.cfm)

Figure 14. A Screenshot of NREL's Residential Efficiency Measures Database

3.3.4. US DOE – Building Technologies Office's Prioritization Tool

http://energy.gov/eere/buildings/prioritization-tool

US DOE's Building Technologies Office is developing an analytical tool that "considers building energy efficiency measures and technologies, and assesses and compares their potential value into the future" ([33]). Farese et al. 2012 ([34]) identifies over 770 energy efficiency measures[8] and provides more detailed information on the methodologies of the tool. Table 25 shows key elements of the input data collected from hundreds of sources for the prioritization tool.

Table25. Key Elements of Energy Efficiency Measures as Input Data Used in the Prioritization Tool

Source: NREL ([34])

Category	Description
Sector	Residential; Commercial; Industrial; Outdoor
Energy Savings	Expressed in the percentage savings over the baseline
Price	The present value of the price difference per unit between the existing mix of "inefficient" technologies and measure being analyzed
Unit & Capacity	Assumed typical equipment size or quantity needed per unit stock
Market	Brief description of the market; Estimated the market size in 2030
Site Use	Known as end use, energy in trillion Btu (TBTUs) per year in 2030
Source Use	Primary or total, energy in TBTUs per year in 2030
CCE	Cost of Conserved Energy in $/MMBTU
Life	Average lifetime

[8] The tool defines Measure as *"a change a change in the technology, system, behavior, or other aspects of energy used to provide a given service. Examples applicable to the BTP include researching and developing light emitting diodes to replace existing, less efficient light sources; developing technical specifications for rooftop units; and developing and enforcing minimum efficiency standards for home refrigerators."* ([34])

Chapter 4 LBNL Database of Energy Efficiency Measures

4.1. Categorization of Energy Efficiency Measures

Based on the sources discussed above, we integrated information on energy efficiency measures (technologies) into a unified format of spreadsheet database. While we use various sources for energy efficiency measures across sectors, it is important to note that original information in detail may differ in definition, scope and basis (e.g., baseline year, baseline technology). We provide notes, depending on specific information for clarification, as well as eliminate unnecessary data for consistency. Table 26 summarizes key elements of the database.

Table26. Key Elements included in LBNL's Energy Efficiency Measures DB V1.0

<table>
<tr><th>Sector</th><th colspan="3">Measure Category (Sub-categories)</th><th>Data</th></tr>
<tr><td>Residential</td><td colspan="3">· Air flow (air leakage, ventilation)
· Appliances, Electronics
· Ceiling / Roofs
· Cooking
· Foundation / Floors
· Lighting
· Refrigeration
· Space conditioning (heating and cooling etc.)
· Walls
· Water heating
· Windows / Doors</td><td rowspan="3">·
· Category
· Sub-category
· Measure / Technology
· Efficiency
· Improvement Potential (%)
· Cost
· Notes
· Year (technology reviewed or reference published)
· References</td></tr>
<tr><td>Commercial</td><td colspan="3">· Air Flow (air compressors, ventilation)
· Ceiling / Roofs
· Cooking
· Lighting
· Major equipment
· Office equipment
· Electronics (Sensors / Controls)
· Transformers
· Walls
· Water heating
· Windows / Doors</td></tr>
<tr><td>Industrial</td><td>Cross-cutting
· Steam Systems
· Electric Motor Systems
· Building energy efficiency</td><td>Industry-specific
· Petroleum refining
· Iron and Steel
· Petrochemical
· Pulp and Paper
· Cement</td><td>Emerging
· Cement
· Iron and Steel
· Pulp and Paper
· Textile</td></tr>
</table>

4.2. Residential Sector Energy Efficiency Measures

The database v1.0 includes total about 300 energy efficiency measures in the residential sector. Table 27 summarizes energy efficiency measures for residential sector in the database v1.0.

Table27. Residential Sector Energy Efficiency Measures in LBNL's DB v1.0

Category	Sub-category	Number of Measures in DB V1.0
Appliances / Electronics	▪ Clothes washers / dryers ▪ Cooking ▪ Controls ▪ Dish washers ▪ Personal computers / Displays ▪ Refrigerators / freezers ▪ Televisions	81
Ceiling / Roofs	▪ Attic ▪ Radiant barriers ▪ Roofs	15
Foundation / Floors	▪ Basement ▪ Crawlspace ▪ Floors ▪ Slab	16
Lighting	▪ General service / fixtures ▪ Decorative ▪ Downlights ▪ Track lighting ▪ Small direction ▪ Controls	40
Heating, Ventilating, and Air Conditioning (HVAC)	▪ Air leakage ▪ Ventilation ▪ Cooling - air conditioning, fans ▪ Heating – boilers, furnaces & radiators, heaters	76
Walls	▪ Wall general ▪ Wall sheathing ▪ Wood stud ▪ Exterior finish	16
Water	▪ Faucets ▪ Showerheads ▪ Sinks ▪ Water heaters	35
Windows / Doors	▪ Doors ▪ Skylights ▪ Windows	21
Miscellaneous		8
	Total	308

Key References: [14], [15], [16], [32], [34], [37], [38], [40]

4.3. Commercial Sector Energy Efficiency Measures

The database v1.0 includes total about 280 energy efficiency measures in commercial sector. Table 28 summarizes energy efficiency measures for commercial sector in the database v1.0.

Table28. Residential Sector Energy Efficiency Measures in LBNL's DB v1.0

Category	Sub-category	Number of Measures in DB V1.0
Ceiling / Roofs / Walls	· Roofs · Walls	12
Cooking	· Broilers · Fryers · Griddles · Ranges · Steam cookers	35
Major Equipment / Electronics	· Clothes dryers, clothes washers · Dish washers · Refrigerators, Freezers · Ice machines · Personal computers / Displays · Sensors / Controls	55
Heating, Ventilating, and Air Conditioning	· Air conditioning · Air dryers · Boilers · Chillers · Compressors and air compressed systems · Sensors / Controls · Furnaces / Radiators · Ventilation	55
Lighting[a]	· Lamps · Ballasts, Fixtures · Sensors / Controls	38
Motor Systems	· Motors · Pumps · Fans	18
Water	· Controls · Faucets · Water heaters	21
Windows / Doors	· Doors · Skylights · Windows	14
Miscellaneous		28
	Total	276

[a] "Lighting" sheet in the DB summarizes technical information by sector based on a recent US DOE report ([40]).

Key References: [14], [19], [31], [34], [40], [41], [42]

4.4. Industrial Sector Energy Efficiency Measures

The database v1.0 divides energy efficiency measures in three parts; cross-cutting industrial systems, industry-specific measures, and emerging technologies. Table 29 summarizes energy efficiency measures for the industrial sector in the database v1.0.

Table29. Industrial Sector Energy Efficiency Measures in LBNL DB v1.0

	Category	Sub-category	Number of Measures in DB V1.0
Cross-cutting	Energy Management and Building Energy Efficiency	HVAC; Lighting	27
	Steam Systems	Steam supply: boilers, CHP; Steam distribution; Heating, Cooling, and Process integration; Distillation	74
	Motor Systems	Motors; Fans; Pumps; Compressed air systems	64
	Sub-total		165
Industry-specific	Cement	Raw materials preparation; Clinker making; Finish grinding; General	65
	Iron and Steel	Steelmaking; Secondary steelmaking; Integrated steelmaking	75
	Petroleum Refining	Alkylation unit (AKU); Catalytic cracking unit (CCU); Coking unit (CKU); Desalter, crude distillation unit (CDU), VCU (Vacuum crude unit); Hydrocracking unit (HCU); Hydrotreating units (HTU); Isomerization unit (ISU); Offsite systems	Total 363 measures in 34 measure groups
	Petrochemical	Ethylene production; Aromatics; Polymers; Ethylene Oxide / Ethylene Glycol (EO / EG); Ethylene Dichloride / Vinyl Chloride Monomer (EDC / VCM); Styrene; Acrylonitrile; Toluene diisocyanate	29
	Pulp and Paper	Chemical pulping; Chemical recovery; Mechanical pulping; Pulp bleaching; Papermaking	23
	Sub-total		555
Emerging	Cement	Grinding; Kiln, Alternative raw materials; Carbon capture and storage	7
	Iron and Steel	Agglomeration; Coke-making; Iron-making using blast furnace; Alternative iron-making; Casting; Rolling and Finishing; Recycling and waste reduction; Carbon capture and storage	56
	Pulp and Paper	Pre-treatment; Pulping; Papermaking; Byproducts/ Biomass/ Waste Heat Utilization; Carbon capture and storage	45
	Textile	Spinning; Weaving; Wet processing; Sensor and control	20
	Sub-total		128
		Total	848

[a] "Lighting" sheet in the DB summarizes technical information by sector based on a recent US DOE report ([40]).

Key References: [14], [23] - [28], [35], [36]

Summary and Discussion

Based on the information and analysis presented in this report and discussed above, we compiled energy efficiency measures assessed in the residential, commercial, and industrial sectors of the U.S. in one spreadsheet file. For more than 1,200 measures, the database offers efficiency or improvement potential, technical notes, and costs for a given year, where applicable. Key efficiency measures could offer significant opportunities for cost-effective energy efficiency improvement. We summarize conclusions that are relevant for policymakers and program managers when designing effective energy efficiency market transformation programs, as follows:

- Some U.S. states have developed their own energy efficiency measure databases in support of designing various energy efficiency policies and programs.
- An energy efficiency measures database needs to be easy to update and upgrade, as there are emerging and rapidly evolving energy-efficient technologies, e.g., LEDs in lighting sector.
- When designing energy efficiency programs, it is necessary to assess cross-cutting technologies that are applicable to a wide range of industries and sectors, e.g., sensors and controls for energy management, motor systems, lighting and displays (e.g., LEDs/OLEDs), etc.

A robust database of energy efficiency measures can contribute to determining more realistic and accurate savings targets and target stringency under an energy efficiency policy such as an EERS. However, as energy efficiency, i.e., diffusion of energy efficient technologies in a market, is limited by several factors (often referred to as market failures), a systematic financial consideration for efficiency measures, e.g., assessment of cost-effectiveness that leads to cost-effective efficiency targets, needs to be considered for future research, which can help policy makers more appropriately design an energy efficiency policy.

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Appendix A. Resources for Energy Efficiency Measures, Technologies and Programs

Topic Area / Sector	Sub-area	Title	Organization	Authors	Year s Released/ Updated/ Published	Link
EE Policies and Programs		Energy Efficiency Resource Standard (EERS)	ACEEE	-	2014	http://www.aceee.org/topics/eers
EE Policies and Programs		Energy Efficiency Resource Standards: A New Progress Report on State Experience. Report Number U1403	ACEEE	Annie Downs, Celia Cu	2014	http://aceee.org/sites/default/files/publications/researchreports/u1403.pdf
EE Policies and Programs		Energy Efficiency Resource Standards: A New Progress Report on State Experience. Report Number U112	ACEEE	Michael Sciortino, Seth	2011	http://www.aceee.org/sites/default/files/publications/researchreports/u112.pdf
EE Policies and Programs		The Future of Utility Customer-Funded Energy Efficiency Programs in the United States: Projected Spending and Savings to 2025	LBNL	Galen L. Barbose, Charles A.	2013	http://emp.lbl.gov/sites/all/files/lbnl-5803e.pdf
EE Policies and Programs		State Energy Efficiency Resource Standards: Design, Status, and Impacts	NREL	D. Steinberg, O. Zinaman	2014	http://www.nrel.gov/docs/fy14osti/61023.pdf
EE Policies and Programs		Design of Incentive Programs for Accelerating Penetration of Energy-Efficient Appliances	LBNL	Stephane de la Rue du Can, , Greg	2014	http://www.superefficient.org/en/Resources/~/media/Files/design_of_incentives_programs_for_accelerating_penet
EE Policies and Programs		CEE Program Resources	CEE			http://www.cee1.org/content/cee-program-resources
EE Policies and Programs		Regional Energy Efficiency Database (REED)	Northeast Energy Efficiency			http://www.neep.org/initiatives/emv-forum/regional-energy-efficiency-database
EE Potential		Vermont Electric Energy Efficiency Potential Study	GDS Associates/ VDPS	-	2007	http://publicservice.vermont.gov/sites/psd/files/Topics/Energy_Efficiency/VT%20Final%20Report-Jan07v3.pdf
Energy Consumption and Forecast		Annual Energy Outlook	EIA	-	Annual	http://www.eia.gov/forecasts/aeo/
Res	Buildings	Optimizing Energy Savings from Direct-DC in U.S. Residential Buildings	LBNL	Garbesi, Karina, Vagelis Vossos,	2011	http://eetd.lbl.gov/publications/optimizing-energy-savings-direct-dc-us-residential-buildings
Res	Roofs	Roof and Attic Design Guidelines for New and Retrofit Construction of Homes in Hot and Cold Climates	ORNL	William Miller, Andre Desjarlais,	2008	http://web.ornl.gov/sci/buildings/2012/2013%20B12%20papers/161_Miller.pdf
Res	Clothes Dryers	Evaluation of energy efficiency standards for residential clothes dryers in the USA	LBNL	Lekov, Alexander B., Victor H.	2013	http://eetd.lbl.gov/publications/evaluation-of-energy-efficiency-standards-for-residential-clothes-dryers-in-the-
Res	Game Consoles	Video game console usage and national energy consumption: Results from a field-metering study	LBNL	Desroches, Louis-Benoit, Jeffery B.	2013	http://eetd.lbl.gov/publications/video-game-console-usage-and-national
Res	Lighting	Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates	KEMA, PNNL/ USDOE	-	2012	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_residential-lighting-study.pdf
Res	Refrigerators	Superefficient Refrigerators: Opportunities and Challenges for Efficiency Improvement Globally	LBNL	Nihar Shah, Won Young Park,	2014	http://www.superefficient.org/Resources/~/media/Files/ACEEE%202014%20Summer%20Study%20-
Res	Refrigerators	Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers	US DOE	-	2011	http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0043-0024
Res	Refrigerators	Energy use of U.S. residential refrigerators and freezers: function derivation based on household and climate characteristics	LBNL	Greenblatt, Jeffery B., Asa S. Hopkins,	2013	http://eetd.lbl.gov/publications/energy-use-of-us-residential-refriger

Res	Room ACs	Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners	LBNL, Navigant	Shah, Nihar, Paul Waide, and Amol	2013	http://www.superefficient.org/Resources/~/media/Files/SEAD%20Technical%20Analysis%20Reports/SEAD%20Room
Res	Room ACs, Clothes Dryers	Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment. Residential Clothes	US DOE		2011	
Res	TVs	Efficiency improvement opportunities in TVs: Implications for market transformation programs	LBNL	Won Young Park, Amol Phadke,	2013	http://www.superefficient.org/en/Products/~/media/Files/SEAD%20Technical%20Analysis%20Reports/SEAD%20TV
Res	TVs	3D Television Sets Research Report	Navigant	Anthony Rotolo, Kevin Morrissey,	2013	http://www.superefficient.org/Resources/~/media/Files/SL%20Project%20Reports/SEAD%203D%20Television%20Se
Res	Water Heaters	Energy Efficiency Design Options for Residential Water Heaters: Economic Impacts on Consumers	LBNL	Lekov, Alexander B., Victor H.	2011	http://eetd.lbl.gov/publications/energy-efficiency-design-options-residential-water-heaters-economic-impacts-
Res	Network Equipment	Small Network Equipment Energy Consumption in U.S. Homes - Using Less Energy to Connect Electronic Devices	NRDC	Noah Horowitz, Gregg Hardy,	2013	http://www.nrdc.org/energy/files/residential-network-IP.pdf
Res		U.S. Residential Energy Consumption Survey (RECS)	US EIA		1979, 1980, 1981, 1982,	http://www.eia.gov/consumption/residential/
Res		National Residential Efficiency Measures Database	NREL			http://www.nrel.gov/ap/retrofits/about.cfm
Com	Buildings	Energy Efficiency Potential in Existing Commercial Buildings: Review of Selected Recent Studies	PNNL	DB Belzer	2009	http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18337.pdf
Com	Buildings	Grocery Store 50% Energy Savings Technical Support Document	NREL	Matthew Leach, Elaine Hale, Adam	2009	http://www.nrel.gov/docs/fy09osti/46101.pdf
Com	Buildings	Technical Support Document: Strategies for 50% Energy Savings in Large Office Buildings	NREL	Matthew Leach, Chad Lobato,	2010	http://www.nrel.gov/docs/fy10osti/49213.pdf
Com	Lighting	Lighting Controls in Commercial Buildings	LBNL	-	2012	http://eetd.lbl.gov/sites/all/files/a_meta-analysis_of_energy_savings_from_lighting_controls_in_c
Com		U.S. Commercial Buildings Energy Consumption Survey (CBECS)	US EIA		1979, 1983, 1986, 1989,	http://www.eia.gov/consumption/commercial/
Ind	Data Center	Data Center Efficiency Assessment - Scaling Up Energy Efficiency Across the Data Center Industry: Evaluating Key Drivers and Barriers	NRDC	Josh Whitney, Pierre Delforge	2014	http://www.nrdc.org/energy/files/data-center-efficiency-assessment-IP.pdf
Ind	Data Center	Estimating the Energy and Efficiency Potential of U.S. Data Centers	LBNL	Masanet, Eric R., Richard E. Brown,	2011	http://eetd.lbl.gov/node/55482
Ind	Distribution Transformers	Energy Efficiency Potential for Distribution Transformers in APEC economies	LBNL	Virginie Letschert, Michael McNeil,	2013	http://eetd.lbl.gov/sites/all/files/lbnl-6682e.pdf
Ind	Motors	Motor Repairs: Potential for Energy Efficiency Improvement	Econoler/ APEC Expert Group	-	2014	http://www.superefficient.org/Products/~/media/Files/APEC-CAST%20Motor%20Repairs/APEC-
Ind	Manufacturing	U.S. Manufacturing Energy Use and Greenhouse Gas Emissions Analysis	ENERGETICS INCORPORATED /		2012	http://energy.gov/sites/prod/files/2013/11/f4/energy_use_and_loss_and_emissions.pdf

Ind	Petroleum Refining	Assessment of Energy Efficiency Improvement in the United States Petroleum Refining Industry	LBNL	Morrow, III, William R., John	2013	http://eetd.lbl.gov/publications/assessment-of-energy-efficiency-imp-3
Ind	Petrochemical	Energy Efficiency Improvement and Cost Saving Opportunities for the Petrochemical Industry An ENERGY STAR® Guide for Energy and Plant	LBNL	Maarten Neelis, Ernst Worrell,	2008	http://www.energystar.gov/ia/business/industry/Petrochemical_Industry.pdf
Ind	Iron and Steel	Greenhouse Gas Mitigation Options in ISEEM Global Energy Model: 2010-2050 Scenario Analysis for Least-Cost Carbon Reduction in Iron and Steel	LBNL	Nihan Karali, Tengfang Xu,	2013	http://eetd.lbl.gov/sites/all/files/lbnl-6550e.pdf
Ind	Iron and Steel	Reducing energy consumption and CO2 emissions by energy efficiency measures and international trading: A bottom-up modeling for the U.S.	LBNL	Karali, Nihan, Tengfang T. Xu,	2014	http://eetd.lbl.gov/publications/reducing-energy-consumption-and-co2-e
Ind	Iron and Steel	Development of Bottom-up Representation of Industrial Energy Efficiency Technologies in Integrated Assessment Models for the Iron and Steel	LBNL	Xu, Tengfang T., Jayant A. Sathaye,	2010	http://eetd.lbl.gov/node/49943
Ind	Cement	Energy Efficiency Improvement and Cost Savings Opportunities for Cement Making	Utrecht University. LBNL	Ernst Worrell, Katerina Kermeli,	2013	http://www.energystar.gov/buildings/tools-and-resources/energy-efficiency-improvement-and-cost-
Ind	Cement	Bottom-up Representation of Industrial Energy Efficiency Technologies in Integrated Assessment Models for the Cement Sector	LBNL		2010	
Ind	Cement	Energy Efficiency Improvement Opportunities for the Cement Industry	LBNL		2008	
Ind	Dairy Processing	Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry	LBNL		2011	
Ind	Textile	Alternative and Emerging Technologies for an Energy-Efficient, Water-Efficient, and Low-Pollution Textile Industry	LBNL		2013	
Ind	Textile	Energy-Efficiency Technologies and Benchmarking the Energy Intensity for the Textile Industry	LBNL		2012	
Ind	Breweries	Energy Efficiency Improvement and Cost Saving Opportunities for Breweries	LBNL	Christina Galitsky, Nathan	2003	http://www.energystar.gov/sites/default/files/buildings/tools/LBNL-50934.pdf
Ind	Chemical	Energy Use and Energy Intensity of the U.S. Chemical Industry	LBNL	Ernst Worrell, Dian Phylipsen,	2000	http://www.energystar.gov/sites/default/files/buildings/tools/industrial_LBNL-44314.pdf
Ind	Chemical	Carbon Emissions Reduction Potential in the US Chemicals and Pulp and Paper Industries by Applying CHP Technologies	LBNL	Marta Khrushch, Ernst Worrell,	1999	http://www.energystar.gov/sites/default/files/buildings/tools/EmReds.pdf
Ind	Corn refining	Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry	LBNL	Christina Galitsky, Ernst	2003	http://www.energystar.gov/sites/default/files/buildings/tools/LBNL-52307.pdf
Ind	Baking	Energy Efficiency Improvement and Cost Saving Opportunities for the Baking Industry	LBNL	Eric Masanet, Peter Therkelsen,	2012	http://www.energystar.gov/sites/default/files/buildings/tools/Baking_Guide.pdf
Ind	Fruit and Vegetable	Energy Efficiency Improvement and Cost Saving Opportunities for the Fruit and Vegetable Processing Industry	LBNL	Eric Masanet, Ernst Worrell,	2008	http://www.energystar.gov/sites/default/files/buildings/tools/Food-Guide.pdf
Ind	Glass	Energy Efficiency Improvement and Cost Saving Opportunities for the Glass Industry	LBNL	Ernst Worrell, Christina	2008	http://www.energystar.gov/sites/default/files/buildings/tools/Glass-Guide.pdf

Ind	Vehicle Assembly	Energy Efficiency Improvement and Cost Saving Opportunities for the Vehicle Assembly Industry	LBNL	Christina Galitsky and Ernst Worrell	2008	http://www.energystar.gov/sites/default/files/buildings/tools/LBNL-50939.pdf
Ind	Pharmaceutical	Energy Efficiency Improvement and Cost Saving Opportunities for the Pharmaceutical Industry	LBNL	Christina Galitsky, Sheng-	2008	http://www.energystar.gov/sites/default/files/buildings/tools/Pharmaceutical_Energy_Guide.pdf
Ind	Pulp and Paper	Energy Efficiency Improvement and Cost Saving Opportunities for the Pulp and Paper Industry	LBNL	Klaas Jan Kramer, Eric Masanet,	2009	http://www.energystar.gov/sites/default/files/buildings/tools/Pulp_and_Paper_Energy_Guide.pdf
Ind	Concrete	Energy Efficiency Improvement and Cost Saving Opportunities for the Concrete Industry	LBNL	Katerina Kermeli, Ernst Worrell,	2011	http://www.energystar.gov/sites/default/files/buildings/tools/Energy_Efficieny_Improvement_Cost_Saving_Opport
Ind	Iron and Steel	Energy Efficiency Improvement and Cost Saving Opportunities for the U.S. Iron and Steel Industry	LBNL	Ernst Worrell, Paul Blinde,	2010	http://www.energystar.gov/sites/default/files/buildings/tools/Iron_Steel_Guide.pdf
Ind	Cross-cutting	DOE Compressed Air Systems Tools and Resources	US DOE			http://www.energy.gov/eere/amo/compressed-air-systems
Ind	Cross-cutting	DOE Motor Systems Tools and Resources	US DOE			http://www.energy.gov/eere/amo/motor-systems
Ind	Cross-cutting	DOE Process Heating Systems Tools and Resources	US DOE			http://www.energy.gov/eere/amo/process-heating-systems
Ind	Cross-cutting	DOE Pump Systems Tools and Resources	US DOE			http://www.energy.gov/eere/amo/pump-systems
Ind	Cross-cutting	DOE Pump Systems Tools and Resources	US DOE			http://www.energy.gov/eere/amo/steam-systems
Ind		DOE Manufacturing Sector Software Tools	US DOE			https://ecenter.ee.doe.gov/Pages/default.aspx
Ind		U.S. Manufacturing Energy Consumption Survey (MECS)	US EIA		1980, 1984, 1991, 1994,	http://www.eia.gov/consumption/manufacturing/index.cfm
Ind		U.S. Vehicle Energy Consumption Survey (MECS)	US EIA		2005	http://www.eia.gov/consumption/data.cfm#vehicles
Res, Com	Buildings	A Tool to Prioritize Energy Efficiency Investments	NREL	Philip Farese, Rachel Gelman,	2012	http://www.nrel.gov/docs/fy12osti/54799.pdf
Res, Com	Windows	Window-Related Energy Consumption in the US Residential and Commercial Building Stock	LBNL	Joshua Apte and Dariush Arasteh	2006	http://eetd.lbl.gov/sites/all/files/publications/60146.pdf
Res, Com	Windows	Zero Energy Windows	LBNL	Arasteh, Dariush K., Stephen E.	2006	http://eetd.lbl.gov/publications/zero-energy-windows
Res, Com	Ceiling Fans	Efficiency improvement opportunities for ceiling fans	LBNL	Nihar Shah, Nakul Sathaye, Amol	2014	http://www.superefficient.org/Resources/~/media/Files/efficiency_improvement_opportunities_for%20ceiling_fans-
Res, Com	Displays	Efficiency improvement opportunities for personal computer monitors: implications for market transformation programs	LBNL	Park, Won Young, Amol A. Phadke,	2013	http://eetd.lbl.gov/publications/efficiency-improvement-opportunities-

Res, Com		Michigan Energy Measures Database	Michigan Public Service			
Com, Ind	Ceiling Fans	Preliminary Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Ceiling	US DOE	-	2014	http://www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0045-0065
Res, Com, Ind	Appliances and Equipment	Max Tech and Beyond: Maximizing Appliance and Equipment Efficiency by Design	LBNL	Louis-Benoit Desroches,	2011	http://cltc.ucdavis.edu/publication/max-tech-and-beyond-maximizing-appliance-and-equipment-efficiency-design
Res, Com, Ind	Appliances and Equipment	Estimate of Technical Potential for Minimum Efficiency Performance Standards in 13 Major World Economies	LBNL	Virginie Letschert, Louis-Benoit	2012	http://www.superefficient.org/en/Resources/~/media/Files/BUENAS%20BAT%20Scenario-%20LBNL-5724E.pdf
Res, Com, Ind	Appliances and Equipment	Catalog of DC Appliances and Power Systems	LBNL	Karina Garbesi, Vagelis Vossos,	2011	http://efficiency.lbl.gov/sites/all/files/catalog_of_dc_appliances_and_power_systems_lbnl-5364e.pdf
Res, Com, Ind	Buildings	Data and Analytics to Inform Energy Retrofit of High Performance Buildings	LBNL	Hong, Tianzhen, Le Yang, David	2014	http://eetd.lbl.gov/publications/data-and-analytics-to-inform-energy-r
Res, Com, Ind	Lighting	Solid State Lighting R&D Manufacturing Roadmap	US DOE	-	2014	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mfg_roadmap_aug2014.pdf
Res, Com, Ind	Lighting	Solid State Lighting R&D Multi-Year Program Plan	US DOE	-	2014	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2014_web.pdf
Res, Com, Ind	Lighting	Energy Savings Forecast of Solid-State Lighting in General Illumination Applications	Navigant/ US DOE	-	2014	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf
Res, Com, Ind	Lighting	SSL Pricing and Efficacy Trend Analysis for Utility Program Planning	PNNL/ USDOE	-	2012	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_trend-analysis_2013.pdf
Res, Com, Ind	Lighting	2010 U.S. Lighting Market Characterization	Navigant/ US DOE	-	2012	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf
Res, Com, Ind	Lighting	Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications	Navigant/ US DOE	-	2011	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf
Res, Com, Ind	Buildings	DOE Building Energy Software Tools Directory	US DOE			http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm
Res, Com, Ind		U.S. Energy Star qualified products				http://www.energystar.gov/products/certified-products
Res, Com, Ind	Appliances and Equipment	Technical Documents for Appliances and Equipment Standards	US DOE			http://www.regulations.gov/
Res, Com, Ind, Arg		California Energy Efficiency Portal	CPUC			http://eestats.cpuc.ca.gov/